

The
GEOLOGY
and
PETROLOGY
of the
MARBLE DELTA

by

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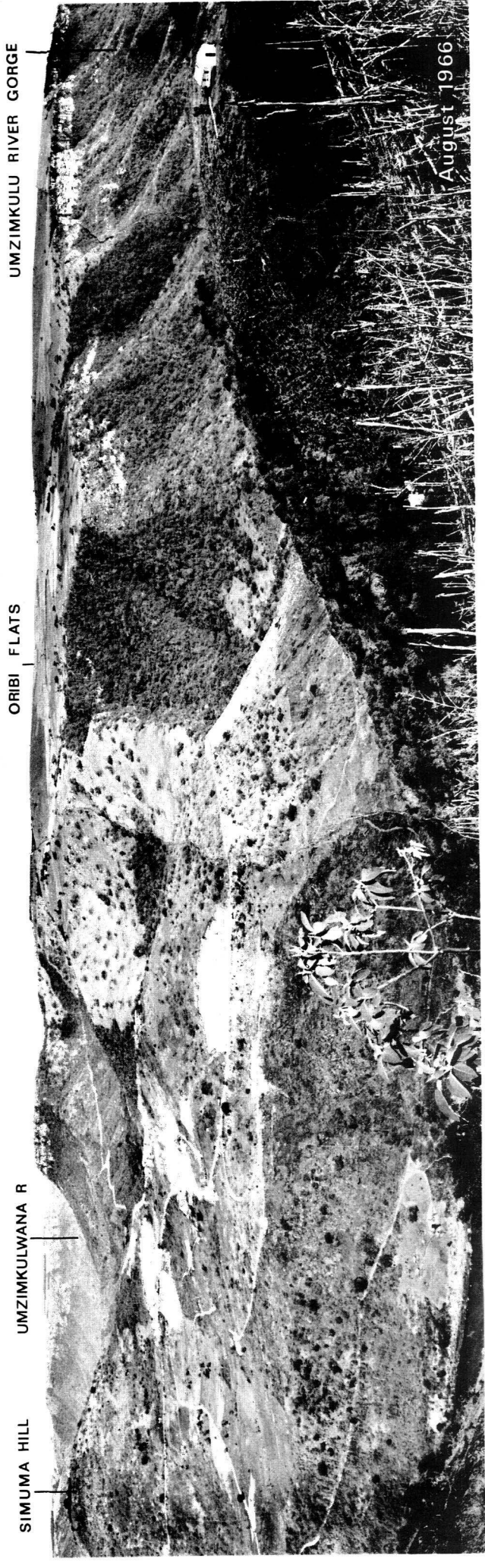
FRONTISPIECE: SOUTHWARD VIEW OF THE MARBLE DELTA



WEST SLOPES

EAST SLOPES

ORIBI LIME QUARRY LYWOOD UMZIMKULWANA R



SIMUMA HILL

UMZIMKULWANA R

ORIBI FLATS

UMZIMKULU RIVER GORGE

August 1966

ABSTRACT

The Marble Delta is an area of approximately 40 sq. km in Natal (30°22' Long., 30°40' Lat.), occupied by Precambrian marble and associated granites. The deeply dissected country was geologically mapped on a scale of 1 : 6 000. A new lithostratigraphic classification of the metasediments is proposed. The base of the lowermost Le Joncquet Formation (composed of dolomitic marble and siliceous beds) is not exposed. This is followed by the predominantly calcitic Oribi Formation with interbedded dolomite and graphitic layers. The marble is unconformably overlain by the Cherrywillingham Formation which comprises mainly amphibolite and granulite. The three formations together constitute the Marble Delta Group.

The main petrological units are calc-silicate marble, metaquartzite, dolomite marble, cluster serpentine marble and calcite marble. Graphite layers are considered to have originated in situ from organic remains; there is occasional evidence of ionic transfer of carbon from this graphite by magmatic fluids. The common mineral assemblages are diopside + calcite + dolomite, tremolite + calcite + diopside + quartz, calcite + quartz + dolomite, forsterite + calcite + dolomite, plagioclase + cordierite + garnet + quartz, amphibole + clinopyroxene + plagioclase, hornblende + clinopyroxene + calcite, wollastonite + calcite + diopside. Other minerals are graphite, antigorite, chrysotile, sphene, spinel, clinohumite, chondrodite, zoisite, clinozoisite, hedenbergite, phlogopite, ilmenite, hercynite, dravite, cummingtonite, talc, apatite, microcline, saponite. The mineral assemblages resulted from regional metamorphism and polyphase contact metamorphism.

Intrusive/

Intrusive amphibolite dykes and sills are not considered to be Precambrian dolerites but they probably crystallized directly from a hydrous basaltic magma as amphibolite. A suite of basic and alkaline rock types in the form of small bodies and dykes comprising hornblende gabbro, syenite, diorite, monzonite, ijolite and melteigite is described for the first time (the N'Dongeni suite).

Granites of different ages are intrusive into the meta-sediments. They exhibit a wide variation in petrological characteristics from the gneissose The Wolds granite to the charnockitic types of the Oribi Gorge granites. The Westlands and Buffalo Bill granites extensively invaded the marble and developed skarn assemblages along the contacts. These intrusions are also associated with oligoclase aplite and other monomineralic dykelets consisting essentially of quartz, microcline or scapolite. A serial variation of lattice parameters probably corresponding to a variation in Ca content was recognised for the mizzonite range of the scapolite series.

"Skarn" is redefined in a purely descriptive sense and a genetic classification of skarn types applicable to the Marble Delta is proposed. The terminology of the principal types (isoskarn, metaskarn, conskarn, magskarn, retroskarn and complex skarn) is already in local use. Some isoskarns display mineral assemblages produced by a process of induced contact metamorphism.

The paragenesis of minerals in the granite dykes is discussed in terms of high P_{CO_2} and closed system conditions which led to the formation of clinopyroxene. Such

conditions/

conditions may also explain the non-formation of wollastonite and stability of calcite-quartz associations.

Coarse-grained dolomite and calcite bodies formerly included with the stratigraphic succession post-date the granites and are present in the form of replacement bodies parallel to the Glen fault system.

Structurally, the marble is a "twisted mass" surrounded by numerous xenolithic bodies in granite. Three periods of deformation have been distinguished: the F_1 structures are all but obliterated in the marble but have been preserved in disjointed blocks of metaquartzite and conglomerate which were broken up during the F_2 folding. The F_2 fold axes have been deduced from the geological map and from lineation directions. The central structure is a skew dome which fingers out southeastwards in a series of curved plunging anticlines and synclines. The F_3 deformation is related to the intrusion of the granites which led to plastic flow of the marble and folding which is not controlled by principal stressfields. This factor was found to impose severe limitations on any regional interpretation based on a petrofabric analysis of the marble. Finally the area is traversed by two prominent fault systems, one of pre-Cape and the other of post-Cape age.

The trend of the foliation in the adjacent granites conform to the structure of the marble which is considered to represent a local deviation from the regional trend of the Namaqua-Natal belt of which it probably forms part on limited geochronological evidence.

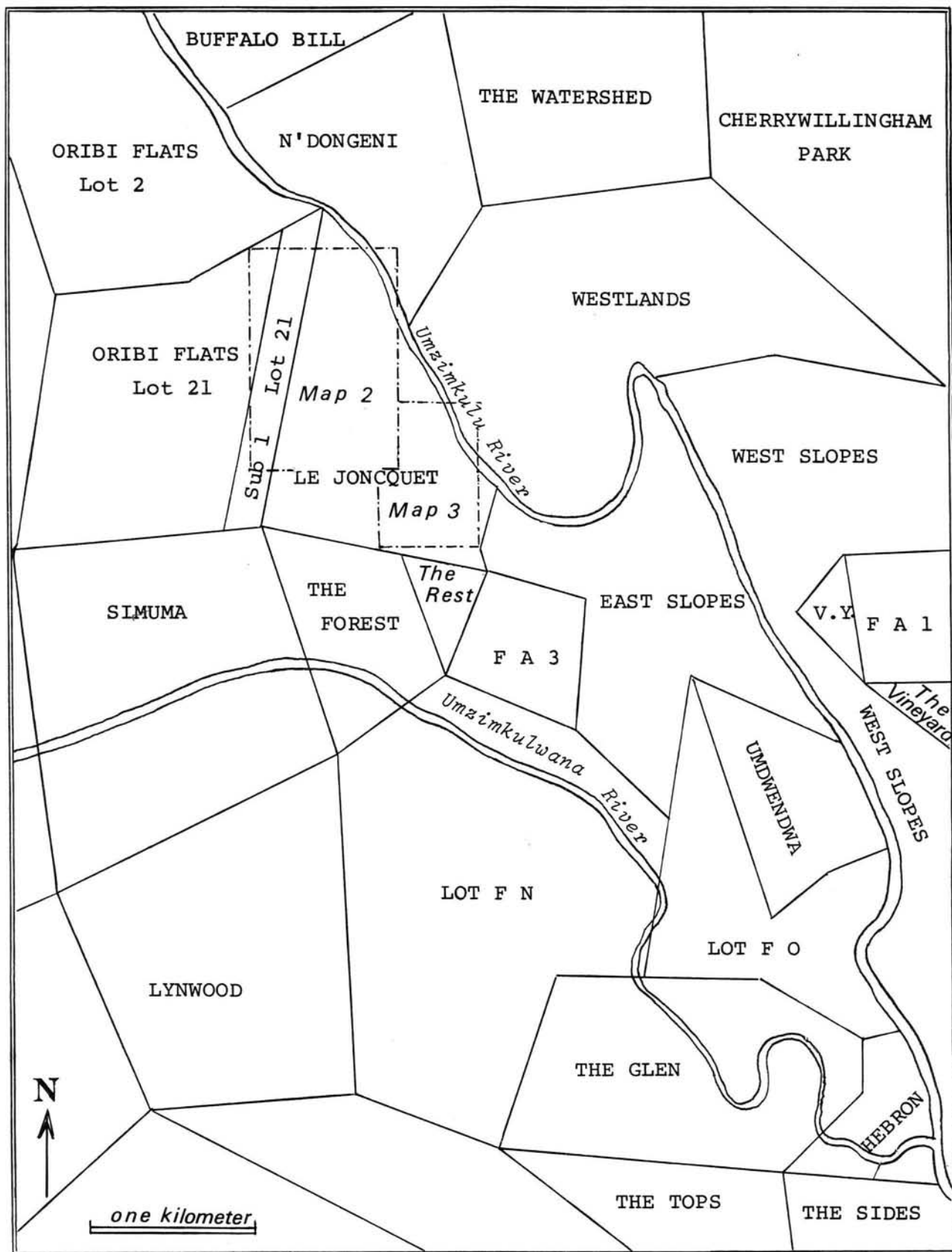


FIGURE 1. Topocadastral map of the Marble Delta

C O N T E N T S

I	INTRODUCTION	1
II	PHYSIOGRAPHY	5
III	THE MARBLE DELTA GROUP	9
	1. Stratigraphy	9
	(a) The Le Joncquet Formation	12
	(b) The Oribi Formation	14
	(c) The Cherrywillingham Formation ..	15
	2. Petrology	17
	(a) Calc-silicate Marble	17
	(b) Dolomite Marble	18
	(c) Cluster Serpentine Marble	22
	(d) Metaquartzite	23
	(e) Calcite Marble	26
	(f) Amphibolite	29
	(g) Clinopyroxene-calcite Marble	32
	(h) Granulite	34
	3. Mineralogy	38
	(a) Calcite	38
	(b) Dolomite	41
	(c) Diopside and other pyroxenes	41
	(d) Forsterite	42
	(e) Serpentine	43
	(f) Wollastonite	44
	(g) Tremolite	45
	(h) Phlogopite	45
	(i) Graphite	48
	(j) Clinohumite	49
	(k) Spinel	50
	(l) Scapolite	51
	(m) Sphene	52

	(n) Talc	53
	(o) Tourmaline	53
	(p) Saponite	56
	(q) Other minerals	57
	4. Chemical Composition	58
IV	PRE-CAPE INTRUSIONS	65
	1. Amphibolite Dykes and Sills	65
	2. N'Dongeni Basic Rocks	68
	(a) Hornblende-pyroxene Gabbro	69
	(b) Mela-diorite	70
	(c) Diorite	71
	(d) Syenite	73
	(e) Theralite, Ijolite and Melteigite	73
	3. Granitic Rocks	76
	(a) The Wolds Granite	78
	(b) St. Helen's Rock Granite	81
	(c) St. Faith's Granite	81
	(d) Westlands Granite	84
	(e) Umzimkulwana Granite	87
	(f) Oribi Gorge Granites and Charnockitic Rocks	88
	(g) Buffalo Bill Granite	89
	(h) Granite Dykes	91
	(i) Oligoclasite aplite	102
	(j) Monomineralic Dykelets related to Granite	103
V	SKARN	109
	1. Definition	109
	2. Classification	110
	3. Examples	115

VI	CARBONATE REPLACEMENT BODIES AND VEINS	120
	1. Ferruginous Dolomite	120
	2. Late Calcite	123
VII	SUPRACRUSTAL FORMATIONS	124
	1. Table Mountain Sandstone	124
	2. Dwyka Tillite	125
	3. Karoo Dolerite	126
VIII	STRUCTURAL GEOLOGY	128
	1. Regional Fold Structure	128
	2. Structures related to Intrusions of Granite	132
	3. Petrofabrics	134
	4. The Glen and Renken Fault Systems	138
IX	PETROGENESIS	141
	1. Sedimentation	141
	2. Origin of Amphibolite	147
	3. Metamorphism	152
	4. Emplacement of Granites	158
X	SUMMARY AND CONCLUSIONS	159
	ACKNOWLEDGEMENTS	162
	REFERENCES	163

LIST OF PLATES

- FRONTISPIECE. Southward view of the Marble Delta.
- PLATE I Pm 1. Calc-silicate marble: texture.
 Pm 2. Quartzitic layers in marble.
- PLATE II Comparative textures in dolomite marble.
- PLATE III Pm 1. Parallel growth of calcite and dolomite.
 Pm 2. Dolomite spindles in recrystallized calcite.
- PLATE IV Comparative structures in quartzitic layers.
- PLATE V Pm 1. Quartz-calcite marble.
 Ph 2. Layered amphibolite.
- PLATE VI Pm 1. Lamellar twinning in pyroxene.
 Pm 2. Hornblende in clinopyroxene marble.
- PLATE VII Pm 1. Lamellar twinning in dolomite.
 Pm 2. Lamellar twinning in corroded dolomite.
- PLATE VIII Ph 1. Altered amphibolite.
 Pm 2. Corroded spinel in calcite marble.
- PLATE IX Pm 1. Hexagonal plate of graphite.
 Ph 2. Graphite band.
- PLATE X Ph 1. Tourmaline in calcite marble.
 Ph 2. Saponite in dolomite marble.
- PLATE XI Pm 1. Gabbro with scapolite.
 Pm 2. Diorite (sphene rim on ilmenite).
- PLATE XII Pm 1-2 Ijolite; aegirine-augite rimmed by garnet.
 Pm 2-4 Ijolite; rounded pyrite grains.

- PLATE XIII Ph 1. St. Faith's granite; cross-cutting dyke.
 Ph 2. St. Faith's granite; aplitic segregation.
 Ph 3. St. Faith's granite; flattened inclusion.
- PLATE XIV Ph 1. Westlands granite dyke in marble.
 Ph 2. Granite dykelet, induced metamorphism.
- PLATE XV Calcite Quarry, granite intrusions.
- PLATE XVI Ph 1. Microcline, deuteric reaction.
 Ph 2. Twinned chalcopyrite.
- PLATE XVII Ph 1. Resorbed microcline in granite.
 Ph 2. Resorbed calcite in pyroxene.
- PLATE XVIII Ph 1. Myrmekite and synantectic growth.
 Ph 2. Myrmekite in resorption embayment.
- PLATE XIX Ph 1. Quartz dykelet.
 Ph 2. Microcline intrusion.
- PLATE XX Ph 1. Microcline dykelet.
 Ph 2. Serpentine banding.
- PLATE XXI Amphibolite dykelet; induced skarn.
- PLATE XXII Northward view of the processing plant.
- PLATE XXIII Deformed conglomerate in metaquartzite.
- PLATE XXIV Ph 1. Flow folds in layered amphibolite.
 Ph 2. Dismembered amphibolite dykelet.

LIST OF FIGURES

- FIGURE 1 Topocadastral map of the Marble Delta.
- FIGURE 2 Stratotype of the Oribi and Le Joncquet Formations.
- FIGURE 3 Amphibolite layer in the Oribi Formation.
- FIGURE 4 Tourmalines in the Marble Delta.
- FIGURE 5 Mineral paragenesis of a granite dyke.
- FIGURE 6 Diffractograms of scapolites.
- FIGURE 7 Isovolumetric comparison of ions/unit skarn.
- FIGURE 8 Structural sketch map of F_2 folding.
- FIGURE 9 Perspective drawing of F_2 lineation.
- FIGURE 10 Ptygmatic folding.
- FIGURE 11 Differential flowage of marble.
- FIGURE 12 Glen and Renken fault system.
- FIGURE 13 Compositional folds of original calcareous sediments.

LIST OF TABLES

- TABLE 1 Modes of calc-silicate marble.
- TABLE 2 Chemical analyses and norms of dolomite marble.
- TABLE 3 Chemical analyses of layers in Le Joncquet Formation.
- TABLE 4 Chemical analyses and norms of calcite marble.
- TABLE 5 Chemical analyses and norms of quartz-calcite marble.
- TABLE 6 Chemical analyses of amphibolites.
- TABLE 7 Volumetric modes of dioritic rocks.
- TABLE 8 Volumetric modes of Buffalo Bill granite.

TABLE	9	Minerals related to dyke-width.
TABLE	10	Chemical analysis of oligoclasite.
TABLE	11	Genetic classification of skarns.
TABLE	12	Chemical analyses of replacement dolomite.
TABLE	13	$\delta^{13}\text{C}$ values of marble and replacement dolomite.

I INTRODUCTION

The area studied lies about 8 km north of Port Shepstone, Natal, ($30^{\circ}22'$ Longitude and $30^{\circ}40'$ Latitude) and forms part of the large erosion window of pre-Cape rocks exposed along the coastal belt of Natal. It occupies some 40 sq km built mainly of Precambrian marble and associated granites in the deeply dissected Umzimkulu Valley. The marble occurs in the shape of a roughly oval area, 7 km in maximum diameter, with very irregular boundaries and adjoined by numerous smaller xenolithic bodies. It is generally known in geological literature as the "Marble Delta", a name derived from the triangular shape of the portion which was originally exploited by the Marble Delta Company (Hatch and Rastall, 1910) between the Umzimkulu and Umzimkulwana Rivers near their confluence. Du Toit (1918) applied the name in a geographical sense to include about 17 farms (fig. 1) over which the marble was eventually found to extend.

The first workings probably date back to 1866 and by 1920 about 15 quarries were in existence. Draper (1895) mentioned several lime kilns and a small cement factory. All the quarries which were developed before 1958 have since closed down and have become overgrown. The main purpose of the present investigation was to facilitate renewed exploitation of the marble on a large scale. After the area was geologically mapped in detail, the writer also surveyed and built 16,9 km of access roads and initiated 22 new quarries. It was found that the economic feasibility of any quarrying

operation/

operation in the Marble Delta depended to a very large extent on a correct interpretation of the stratigraphic succession, structural attitude and metamorphic petrology of the marble with special reference to the effects produced by a multitude of granitic intrusions. Today the Marble Delta quarries produce about 40 different products which are unique for their whiteness. These materials are selected according to their grain size and chemical composition (especially MgO , FeO and SiO_2 content) to suit specifications for a wide range of engineering, industrial, building and domestic uses. Most of the marbles are too coarse-grained for ornamental or statuary purposes.

The Marble Delta attracted the attention of geologists from about a hundred years ago up to the present. Sir Roderick Murchison was one of the first to investigate the economic possibilities of the area in 1866 (Lugg, 1949). Griesbach (1871) gave a geological description of the district including the marble occurrences but he could not establish their relationship with the underlying rocks. Draper (1895) and Hatch and Rastall (1910) concluded that some of the granites were older and others were younger than the marble. Anderson (1907) published the first geological reconnaissance map of the area in colour and expressed the opinion that the granite was definitely intrusive into the marble. This was corroborated by Du Toit in several papers (1913, 1918, 1919, 1920, 1946). Du Toit described reaction phenomena between marble and granite magma and proposed a calcitization theory for the production of calcite marble from a dolomitic parent. In 1956 Simpson and Tregidga gave a more detailed petrological

account of the marble and surrounding granite. Regional metamorphism was held to be responsible for the transformation of basic igneous rocks into amphibolite and of granodioritic-monzonitic intrusions into a charnockitic suite. According to these authors all the other rock types were derived from pre-existing sediments, including minor intrusions of granite which were thought to represent secondary magmas produced in situ by partial melting of arenaceous and argillaceous beds. McIver (1963) undertook a comprehensive petrological study of charnockitic rocks along the Natal coast which are probably related to occurrences in the present area. He suggested that orthocharnockite crystallized from a granitic magma under reducing conditions. Otto (1972) proposed that the pyroxene-bearing granites of the Marble Delta could also have crystallized from a granitic magma under high CO₂ pressure, which would have simulated the "dry" conditions of the granulite facies.

The field-work was carried out at intervals between 1958 and 1970 and the results are presented in the form of a geological map on a scale of 1 : 6 000 (Map 1). Among the difficulties encountered were the rugged topography and the densely wooded terrain infested with mambas. The indigenous vegetation was so thick over most parts that survey lines totalling 113,3 km had to be cut. Outcrop mapping was accomplished by means of a Watts Microptic alidade and plane table on scales of 1 : 1 000 to 1 : 6 000. The area was covered by 2041 plane table stations. In the relatively open areas aerial photographs could be used in conjunction

with/

with plane table ground control. About 600 specimens were collected for laboratory study and 450 thin sections were examined.

References in the text to localities in the field are based on two grid systems. Map 1 is divided into blocks on the basis of the Gauss projection $10\ 31^\circ$. A block is denoted by a figure and letter and this is followed by figures denoting quartered blocks and subsequent quartering. Maps 2 and 3 are subdivided according to the new metric trigonometrical grid-system. Instead of the Y co-ordinate a letter of the alphabet is used for the sake of simplicity, followed by a figure denoting the X co-ordinate in decametres.

II PHYSIOGRAPHY

The rugged topography of the marble and amphibolite contrasts markedly with the flatter surrounding countryside underlain by Table Mountain Sandstone and granite. The steep hills of the Marble Delta give way to rolling country forming part of recognisable landsurfaces. The lower-lying area to the east can be equated with the late-Cainozoic planation and it is suggested that this surface is represented within the Marble Delta by Simuma Hill (317 m above msl). Towards the north along the St. Faith's road, the higher surface is correlated with the upper cycle of the late-Cainozoic planation (King, 1967). The plateau extending from Oribi Flats westward is no doubt partly controlled structurally by the nearly horizontal Table Mountain Sandstone and Dwyka Tillite.

These landsurfaces are deeply incised by two rivers forming gorges through the Table Mountain Sandstone and V-shaped valleys in the older formations. Within these valleys river boulder deposits have been preserved on several high level erosion surfaces, although Du Toit (1946) only mentioned the prominent one in the Umzimkulwana Valley at 131 m above msl. He suggested that the river boulder deposit on this bench may be linked with beach boulder deposits in the coastal area. Actually this is one of a series of boulder deposits which extend in the form of terraces down to river level. The highest terrace (167 m above msl) is situated about 500 metres south of the Umzimkulwana River

(Map 1, 7S). Water-worn boulders more than 2 metres in diameter are found here. The altitudes of these terraces were surveyed and the elevations of the more conspicuous ones recorded as follows: 167, 151, 138, 131 and 123 m above msl. The 131 m bench is also the prominent one in the Umzimkulu Valley on the farm Le Joncquet, indicating that at this stage the two rivers had the same base-level. On this bench a deposit of well-worn river boulders overlies both granite and marble. The boulders lie in potholes in the granite about 110 m above river level at site EE 180 (Map 3). The 131 m bench marks a relatively long period of aggradation before the onset of accelerated incision of the entire drainage system. The lowering of base-level of both rivers must have taken place simultaneously, yet the boulder deposits and nick-points between the 131 m bench and river level show no correlation from the one valley to the other. This means that local base levels operated henceforth due to different hydrological or geological conditions in each valley. The topographic expressions (V-shaped valleys and high-level terraces) related to the gradual marine regression can be correlated with similar features of the Umgeni Valley at Durban and possibly with the Pliocene conglomeratic beach deposits described by McCarthy (1967).

The horseshoe-shaped bends in the Umzimkulu and Umzimkulu rivers are considered to be due to a progressive shift of the rivercourses due to resistant rock-types and not to the commonly held belief of an inherited meander pattern from the late-Cainozoic landsurface. The boulder deposits

described/

described above outline the former course of the two rivers at higher elevations. The Umzimkulu horseshoe bend was formed by the migration of rapids on a resistant dyke of Buffalo Bill granite. The rapids moved progressively south-eastwards along the dyke while an adjacent dolerite sill which now lies at a higher elevation was being eroded away. The meander patterns in the Umzimkulwana River are also related to the underlying rocks.

The formation of some caves in the calcite marble dates back to the period when the rivers flowed at a higher level than at present. This is shown by the fact that the caves contain river boulders and clay. On the wide bench on Le Joncquet, funnel-shaped depressions (entonnoirs) are found which probably indicate the presence of underground caverns. A prominent one is shown on map 2, site T 213

The two perennial rivers are depicted on the geological map according to their winter configurations. Abnormal floods often result in a temporary diversion of the river course but it soon resumes its former position down to the minutest detail. This is due, in part, to the resistant granite dykes which cross the course of the river, causing rapids to return to their former shape and size. The location of some of these rapids and the abnormal flood banks are indicated on map 1. The Umzimkulu River is tidal up to its confluence with the Umzimkulwana River near St. Helen's Rock. During winter the Umzimkulu River can be waded through at the following localities: 4F, 7J, 9L, 11J, 13N, 16R, 17V (Map 1). With the abnormal flood of 1959 the river

level rose more than 12 m in many places and it was during this flood that the factory garages, workshops, offices and laboratory were washed away, including the writer's field maps and survey equipment. This flood scoured out much of the 45 m deep Pleistocene river-channel at the coast so that ocean waves travelled up the tidal portion of the river for a few kilometres.

III THE MARBLE DELTA GROUP

1. STRATIGRAPHY

The complete stratigraphic succession is not present as the marble formations have been enveloped by granites in such a manner that neither the base nor the top is exposed. The sediments were furthermore subjected to repeated folding and were also rendered mobile during several stages of recrystallization so that most of the primary sedimentary structures were obliterated. The only indications of original bedding in the marbles are the chemical variations reflected by different assemblages of metamorphic minerals. Because of these complexities the stratigraphic succession will be described merely with reference to a type locality where the sequence of lithological units is best revealed. How far this sequence can be extended laterally is unknown. Outliers as far distant as 38 kilometres at Ubambolo, do not appear to yield additional information on the stratigraphy of the marble formations. The presence of pelitic beds higher in the succession is not ruled out, as shown by the presence of garnet schist inclusions in the porphyritic granites west of the Marble Delta area. The metamorphosed Precambrian sediments on the coast (McIver, 1963) are also correlated with pelites.

Du Toit (1919, 1946) divided the marble formations into an upper and a lower group using a prominent quartzite or "quartz-schist" as his marker horizon. On Du Toit's map (later reproduced by Simpson and Tregidga, 1956) the quartzite is shown to continue up to the western edge of the marble but in fact it swings northward in conformity with the strike



of the enclosing marble. As a result Du Toit erroneously included the lowermost beds on Le Joncquet with his upper group and accepted an oversimplified structural interpretation which is approximately the reverse of that advocated here. Peculiarly enough, these two mistakes cancel each other as far as the stratigraphic sequence is concerned and led Du Toit (1919) to the correct conclusion that the highest beds are found on N'Dongeni. The apparently homogeneous siliceous rocks are difficult to map effectively on a reconnaissance basis and the only way to unravel the stratigraphic sequence is to resort to outcrop mapping. It was found that the prominent quartzite bed is not continuous but consists of numerous detached blocks with a variable dip as a result of ductility contrasts between quartzite and marble. Other quartzite beds are also present in the marble and may be confused with the main quartzite. For these reasons Du Toit's marker horizon is not considered to be the most suitable boundary for the subdivision of the marbles.

Another problem from a stratigraphic point of view is the question whether the calcite marble represents original limestone beds or not. Du Toit (1919, 1920, 1946) ascribed the presence of calcite marble associated with granite bodies to a process of calcitization, whereby magnesia was supposed to be removed from dolomitic marble through the agency of magmatic waters. Bridges (1939) supported this view from his studies on The Glen, but also suggested that dolomitization of calcite marble should not be disregarded in certain areas. Up to the present these theories have been accepted

by all mining companies in the Marble Delta. The granite bodies were consequently regarded as a necessary nuisance in mining operations, in order to exploit the best available calcite. The writer found no field evidence to support any of the aforementioned assumptions, but ascertained that the granite transgressed sharp contacts between calcite and dolomite beds that were mappable lithostratigraphic units in every respect. A greater frequency of the granite-calcite association is ascribed to the different physical characteristics of the two rock types in that the calcite marble was structurally more amenable to accomodate intrusion than the tougher dolomite with its interlocking grain texture.

Several isolated patches of marble lie outside the mapped area. Towards the north-east a number of outcrops are found on Cherrywillingham Park, striking parallel to the main amphibolite in the direction of the Umzumbi River to the east. South of Lynwood quarries isolated marble remnants occur in the granites. To the west the marble units do not terminate against the Renkin fault as indicated on previous maps (Du Toit 1946, Geol. Surv. 1 : 1 000 000 map of S.A., 1970), but crop out along the Umzimkulu River Valley and are overlain by Table Mountain Sandstone.

The marble formations were tentatively correlated by Anderson (1907) with the Swaziland System. The only available geochronological evidence is a K-Ar date on phlogopite (most likely from a dolomite quarry on Lot F 0, site 15U, Map 1) which indicates that one of the last metamorphic events occurred 1018 my ago (Nicolaysen and Burger, 1965).

Taking into account that the regional metamorphism is probably much older than the intrusion of the granites, a close relationship with the Swaziland System cannot be ruled out, but is unproven. No correlation is therefore attempted, but it is proposed that the following formal lithostratigraphic nomenclature should be applied to the metasediments and associated layered amphibolites: the succession as a whole is called the Marble Delta Group comprising three formations viz. the lowermost Le Joncquet Formation, characterised by a preponderance of dolomitic and siliceous rock types, followed conformably by the predominantly calcitic Oribi Formation, both of which are unconformably overlain by the amphibolites and related rocks of the Cherrywillingham Formation. These units are defined below as far as practicable in accordance with the requirements of the South African Code of Stratigraphic Terminology and Nomenclature (Trans. geol. Soc. S. Afr. 74, 111 - 129, 1971).

(a) The Le Joncquet Formation

The accessible part of this formation is exposed to the north of the quartzite-capped hills in the centre of the Marble Delta on the farm Le Joncquet, which is therefore designated as type locality. The best outcrops are located in the small watercourse between X 150 and X 180 (Map 3) and further towards the horseshoe bend of the Umzimkulu River where duplication due to folding unfortunately prevents the construction of a type section.

The stratotype is given in the form of a composite stratigraphic column (fig. 2) of which the lower half is mainly based on bore-hole information and the upper half on a traverse south-east of the Calcite Quarries between control points Y 190 and T 204 (Map 2). The latter locality is the boundary stratotype between the Le Joncquet and Oribi Formations and occurs at the contact between the highest prominent quartzite layer, 1,5 m thick, and the overlying calcite marble. Thus, while the top of the Le Joncquet Formation can be accurately defined, its base is not preserved. A thickness of 446,5 m is represented by the stratotype but this is a minimum figure due to differential flowage of the marble.

The formation can be divided into four members from the bottom upwards, as follows: (i) diopside-forsterite marble intercalated with numerous quartzite lenses, (ii) dolomite marble, (iii) the main quartzite and (iv) the cluster serpentine dolomite marble. The last-mentioned is much better developed south-east of the stratotype. Direct correlation of these members and beds with the adjoining areas is not possible owing to the discontinuity of outcrops, but similar lithological units have been mapped east of the Marble Delta. The main quartzite member, however, can be followed as a marker though it has been broken up into huge blocks that were twisted and scattered during the mobilization of the marble.

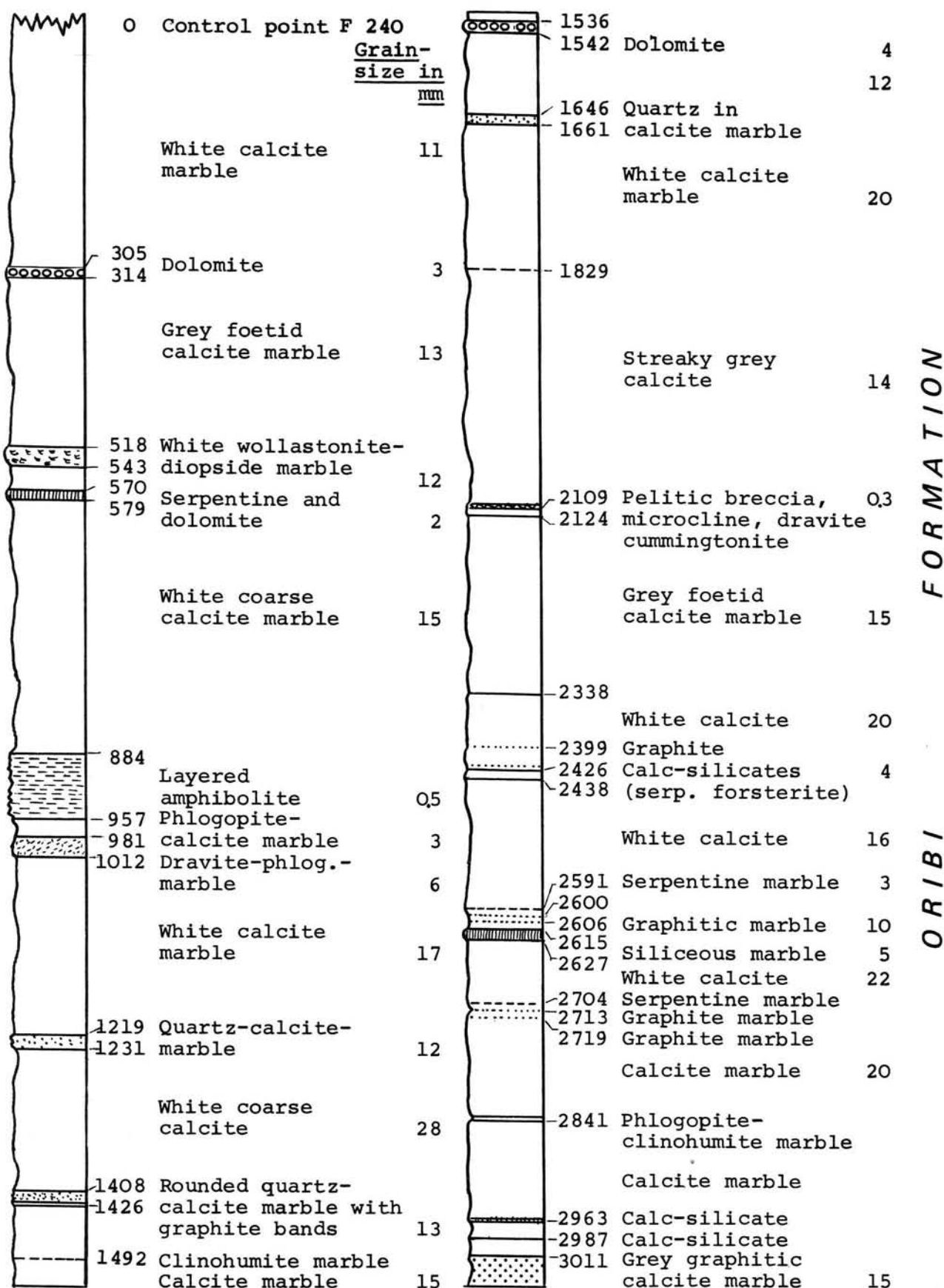


FIGURE 2. Stratotype of Oribi and Le Jonquet Formations showing the more prominent beds, numbered (for reference purposes) in decimetres from an arbitrary control point near the top.

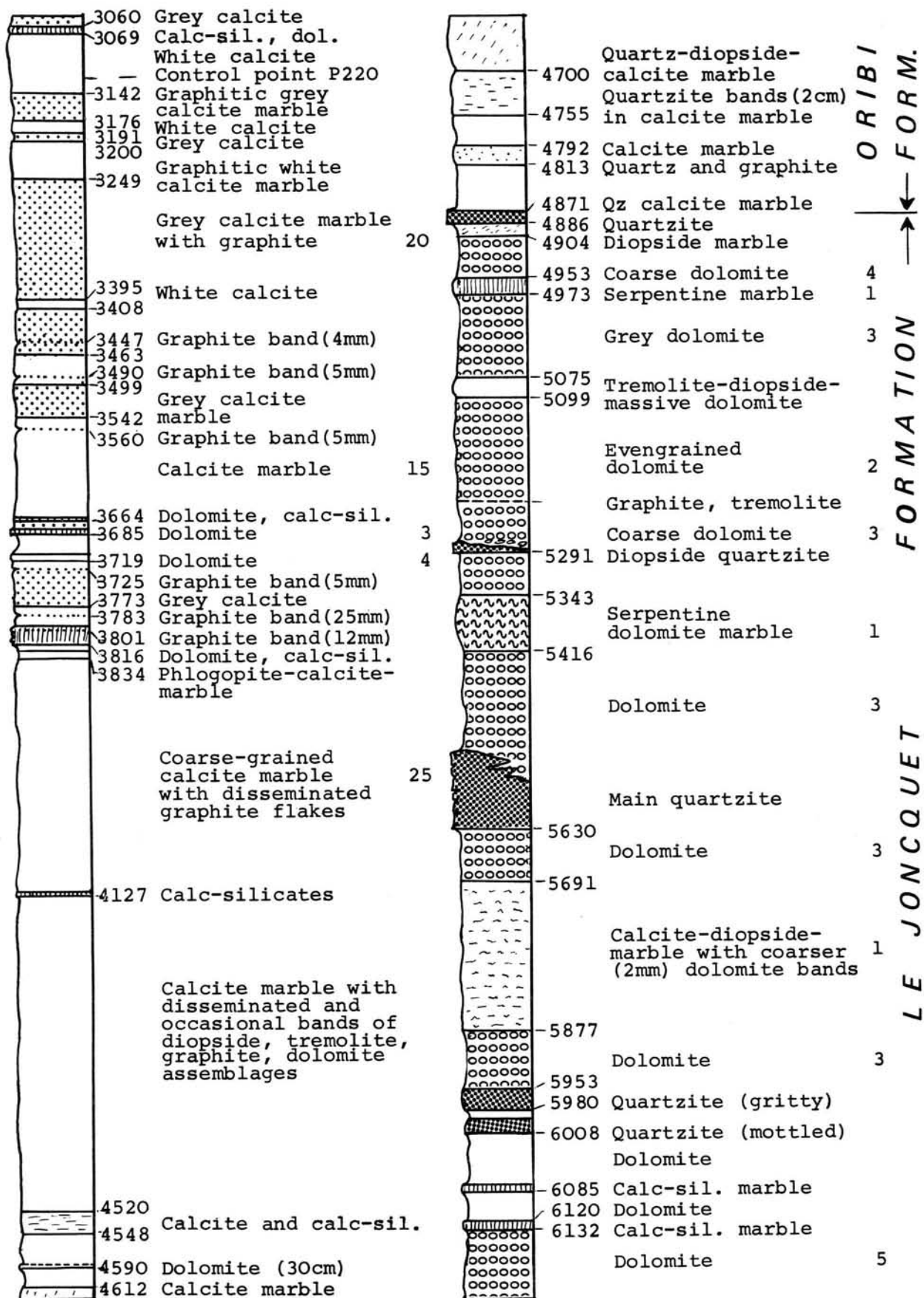


FIGURE 2 (cont.).

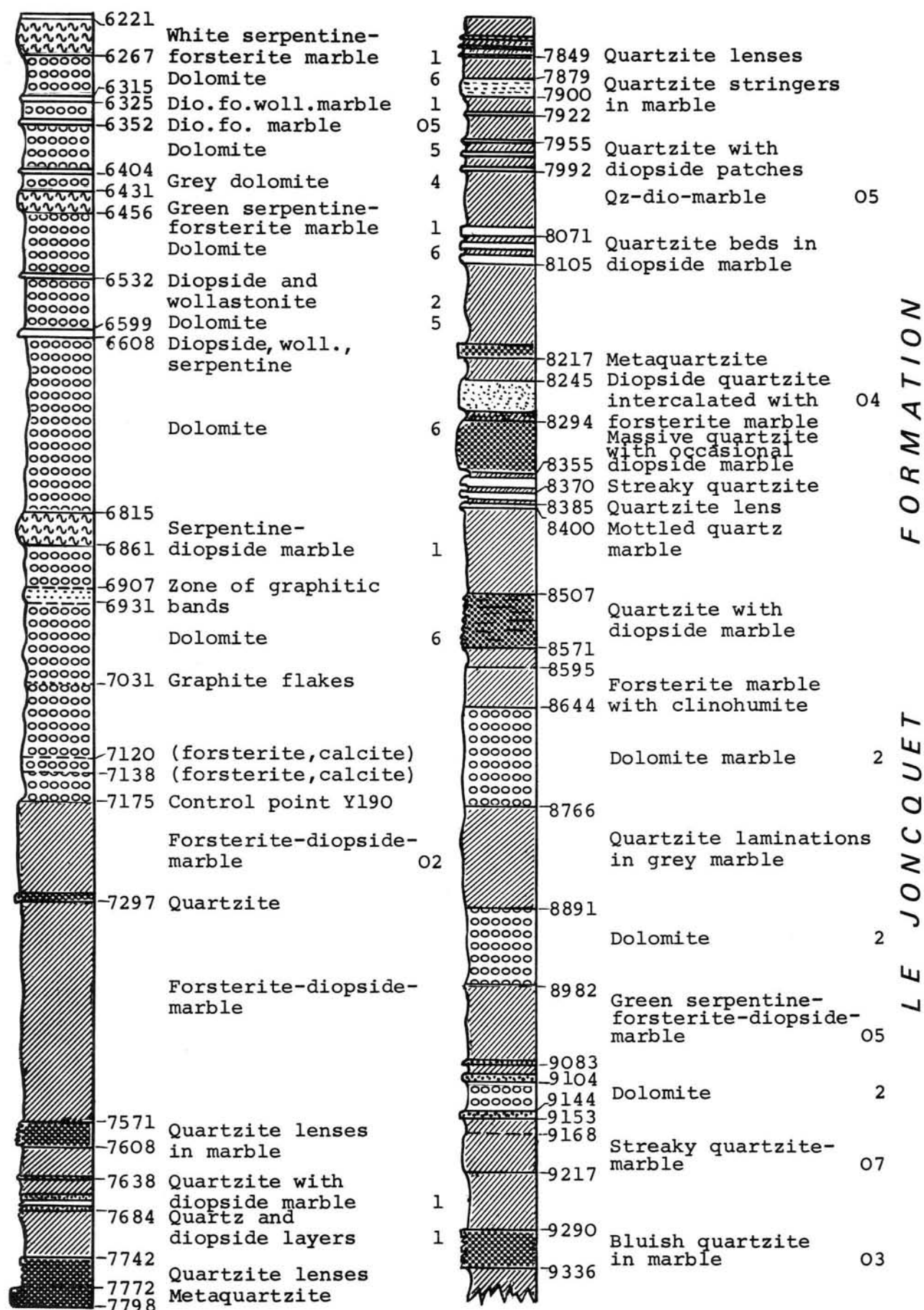


FIGURE 2 (cont.).

(b) The Oribi Formation

The entire known succession of this formation is exposed on Le Joncquet and Oribi Flats (Lot 21). The formation is named after the latter farm where the oribi is still to be found. The base is taken on top of the last quartzite in the dolomite marble sequence which also marks the top of the Le Joncquet Formation, as described above.

The stratotype of the Oribi Formation as shown on fig.2 is again somewhat composite, because it is based on a series of short traverses along trenches and excavations between reference points T204 and F240 in the vicinity of the Calcite Quarries (Map 2). It represents a thickness of 487,1 m but is an incomplete section because it ends rather arbitrarily where repeated folding becomes prominent near the top of the succession on the western part of Le Joncquet and Oribi Flats (Lot 21). The upper boundary is not determinable in any event due to intrusion, deformation and erosion.

The distinguishing feature of the Oribi Formation is the preponderance of calcite marble. The marble does not contain consistent marker horizons to be utilised for field mapping, but a number of beds representing impure limestone layers are recognisable. These beds include intercalations of dolomite marble, siliceous dolomite marble, quartzite and graphite. Attention is also drawn to the presence of layered amphibolite between Bed Nos. 884 and 957 (fig. 2). The layered appearance of the marble was accentuated by plastic flowage, whereas quartzite or impure beds were broken up and retained their thickness-developed during the first period/

period of folding and regional metamorphism. Considerable lateral variation of the above-mentioned layers from one area to another can be deduced from the variable mineral content which represents the variation in chemical composition of the metamorphosed sediments.

Because of lithological similarities the calcite marble in the eastern half of the area as exposed on Vineyard, West Slopes and Lot F O, are regarded as part of this sequence.

(c) The Cherrywillingham Formation

Extensive outcrops of amphibolite and diopside-plagioclase-fels occur on the eastern side of the Marble Delta, especially on the farms West Slopes and Cherrywillingham Park. The latter farm is considered to be the type locality of this predominantly amphibolitic formation which has not been studied in detail. These rocks extend intermittently further east into granite country, as far as the large exposure mapped by Du Toit (1946) in the Umzumbe valley 9 kilometres distant. Map 1 shows that the major outcrops are distributed along the outer fringes of the Marble Delta on the above-mentioned farms, on The Vineyard, The Tops, Hebron, Lot F N and in patches on N'Dongeni. This peripheral arrangement of amphibolitic rocks is taken to indicate that they were deposited or extruded on the Le Joncquet and Oribi Formations and were deformed together with them, as opposed to the view that they are derivatives of intrusive

rocks only. Supporting evidence comes from the well-banded nature of these rocks. The banding is probably due to original flow structures in lava, or bedding in tuffaceous and pelitic sediments. Probably the banding has been somewhat accentuated by metamorphic differentiation, but it contrasts with the massive appearance of amphibolite dykes which do not show banding within the marbles even though they have been subjected to the same intensity of metamorphism. The chemical composition of the amphibolite is rather similar to that of the dykes and sills (Table 6) but shows a higher MgO and lower CaO content.

The Cherrywillingham Formation is structurally conformable with the marble sequence but stratigraphically it overlies both the Le Jonquet and Oribi Formations. On West Slopes the amphibolite occurs close to the quartzite marker of the Le Jonquet Formation whilst about one kilometre further south, beyond Vineyard, it lies on top of the Oribi Formation.

Thin quartzitic beds east of Lot F A 1 bear evidence of sedimentary material included within the Cherrywillingham Formation. Thin layers of greyish black calcite associated with garnetiferous beds and white calc-silicate marble, which occur interlayered with amphibolite on Hebron and The Glen, are also thought to belong to this formation. This particular type of calc-silicate marble has not been encountered in the amphibolite tightly folded into the lower two formations.

2. PETROLOGY

(a) Calc-silicate marble

In this rock type at least 10 per cent of silicate minerals are evenly distributed among relatively fine-grained carbonates. Except for a few beds in the Oribi Formation, calc-silicate marble appears mainly lower down in the Le Le Joncquet Formation. From bed 7175 (fig. 2) downwards, the marble is massive due to fine-grained texture and resistance to weathering. The largest exposure is on the south bank of the Umzimkulu River, on East Slopes and Le Joncquet. The rough surface of the outcrops is due to preferential weathering which leaves residual diopside-tremolite aggregates and trails of quartz. The texture is heteroblastic, with a grain size range of 0,1 - 1 mm. The diopside grains are usually about 0,1 mm with scattered larger poikilitic metacrysts up to 2 mm in diameter.

The main lithological units are made up of the following mineral assemblages which commonly occur in the Le Joncquet Formation:-

1. phlogopite-forsterite-diopside-dolomite-calcite
2. diopside-calcite-dolomite
3. tremolite-calcite-diopside-quartz
4. calcite-quartz-dolomite
5. forsterite-calcite-dolomite

These associations mainly reflect the amphibolite facies of regional metamorphism under special conditions which are further discussed under petrogenesis.

Mottled areas of some beds in the fine-grained diopside-

forsterite/

forsterite marbles are caused by microscopically disseminated flakes of graphite. The flakes occur along boundaries of calcite and dolomite grains, but in grey forsterite-dolomite marble the flakes are stubby and arranged at random. The forsterite is not serpentized to the same extent as in the coarser marbles in the upper Le Jonquet Formation. A thin film of serpentine separates the rounded grains of forsterite from the host of calcite and dolomite (Plate I, pm 1 and Plate III, pm 1).

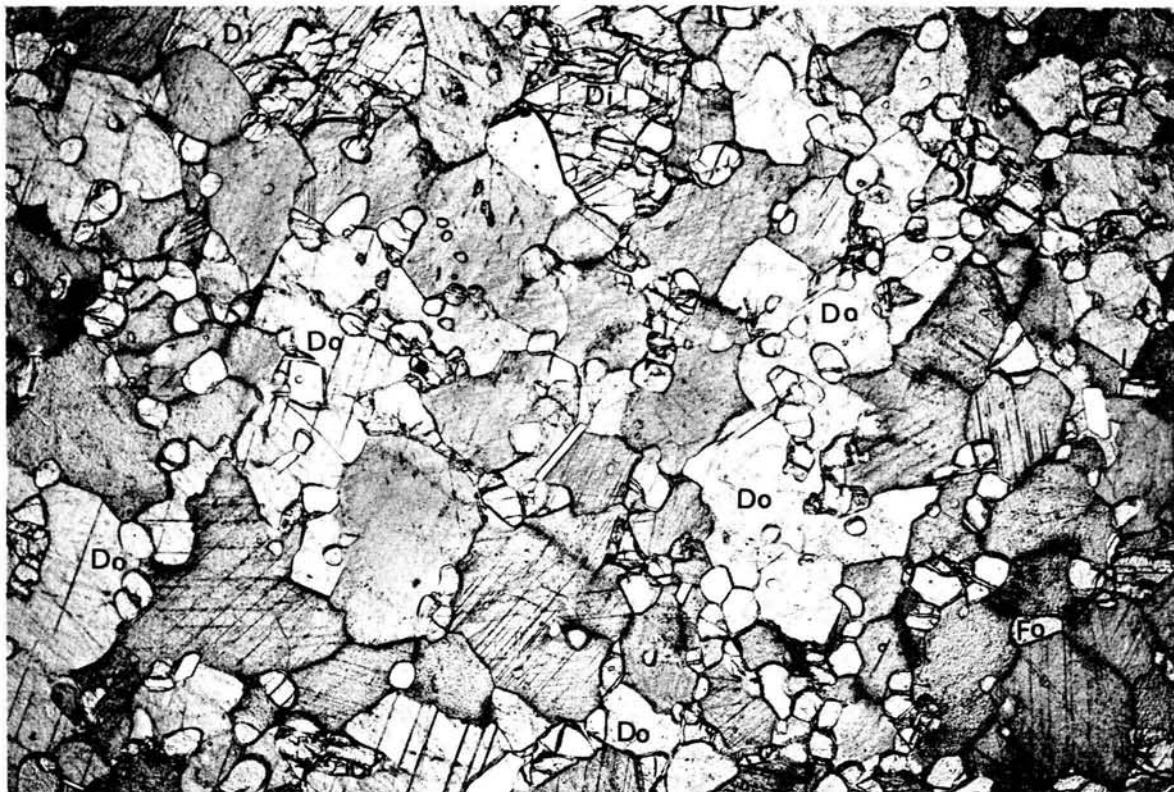
In the more siliceous parts of the calc-silicate marble white streaks of fine-grained diopside and calcite are intercalated with much coarser granoblastic quartz (Plate I, pm 2).

(b) Dolomite marble

The Le Jonquet Formation contains a number of dolomite beds with more than 75% dolomite by volume. The dolomite rock may be easily distinguished in the field from other types of marble, as it exhibits regular pitted surfaces arising from the differential weathering and solution of calcite. Such a surface can usually be distinguished from that of other rock types such as calc-silicate marble, calcite marble and serpentine marble by means of the flashes of reflected light that are visible from the (0001) composition face and (10 $\bar{1}$ 1) cleavage plane of dolomite standing out in relief.

There is a great variation in grain size from one bed to another and also between different localities in the Marble Delta (Plate II). Changes in grain size of any

particular/



Pm 1. Photomicrograph showing heteroblastic texture of calc-silicate marble (Bed No. 9038). Alizarin-stained thin section shows calcite (dark) predominating with dolomite (Do), forsterite (Fo), diopside (Di) and one flake of phlogopite near centre (ordinary light, X28).

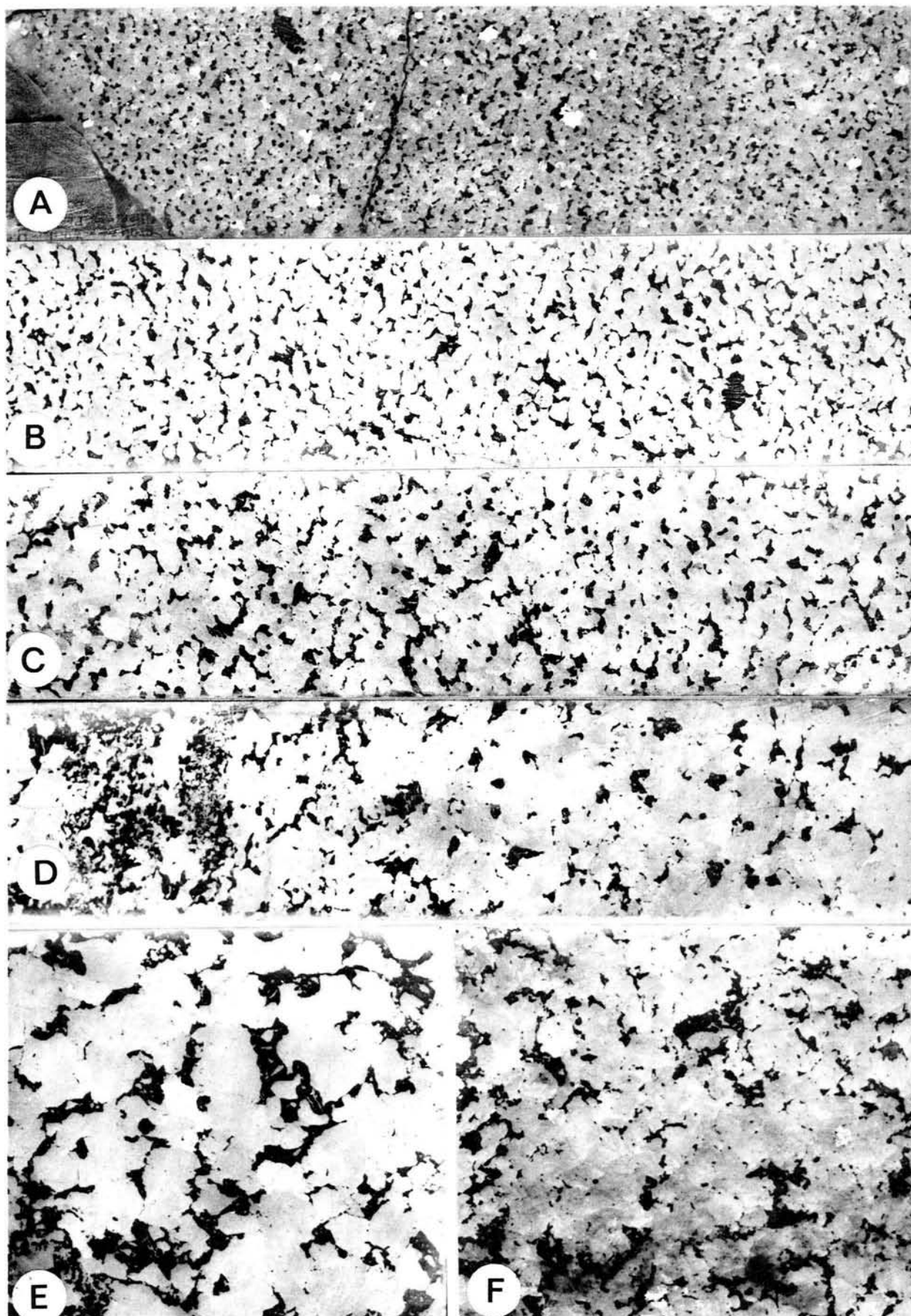


Pm 2. Photomicrograph showing the layered fabric of con-torted quartzitic Bed No. 8565 containing ribbons of calcite and diopside grains. Note that the quartz is relatively free from strain effects. (Crossed nicols, X25).

particular dolomite bed are related to areas of secondary recrystallization and the chemical composition of the beds. In general, the degree of coarseness varies sympathetically with respect to the grain size of nearby calcite marble, though the dolomite is slightly finer grained at any specific locality.

The coarse dolomite member of the Le Joncquet Formation occurs between bed numbers 6008 and 7120 (fig. 2). The dolomite is exceptionally white, with a grain size range of 0,3 - 2 cm and an average of 6 mm. Towards the eastern side of Le Joncquet and towards Lot F 0 this unit holds fewer calc-silicate beds and attains a maximum average grain size range of 1 - 2 cm. The texture of the dolomite is of an interlocking type owing to repeated recrystallization of interstitial calcite. This texture contrasts with the mosaic pattern of the calcite marbles and secondary dolomite bodies. The interstitial calcite in different beds of dolomite marble exhibits distinctive patterns of rods and frayed shapes (Plate II, ph A - F). The interstitial calcite coalesces to form rounded calcite-free areas which are usually twice the size of the dolomite grains, thus forming a secondary grain pattern which is typical of any specific locality. The different textural patterns are probably related to temperatures and pressures operative at the time of recrystallization of the last major episode of metamorphism. Several ages of recrystallization have been deduced from the interstitial calcite, each representing a different localised direction of applied pressure as will be discussed

further/

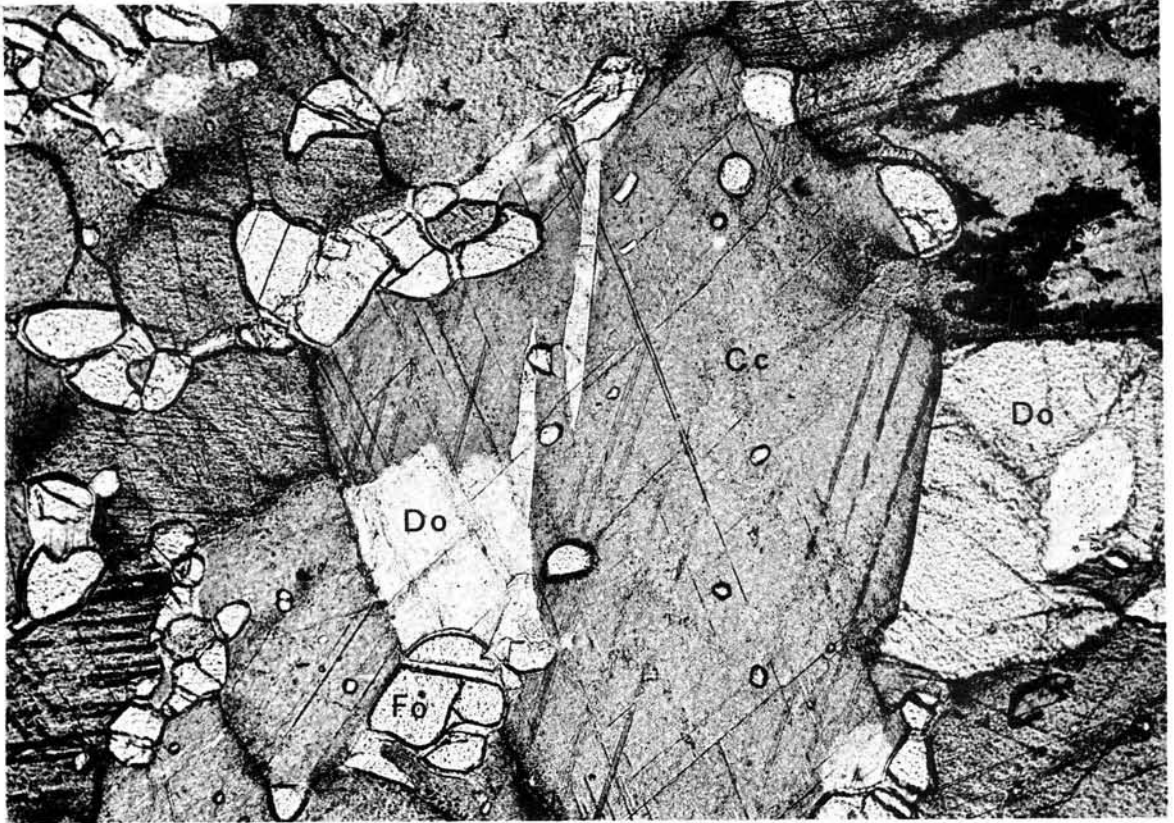


The textural variation of dolomite marble is shown in photographs A to F representing Bed Nos. 5432, 5227, 5066, site FF 154, Lot F O and Bed No. 6815 on level W105. The interstitial alizarin-stained calcite (dark) varies in grain size concomitantly with the dolomite from one layer to another. The white calcite-free area, occupied by 3 to 4 dolomite grains also varies in line with grain size. (Actual size ground surfaces)

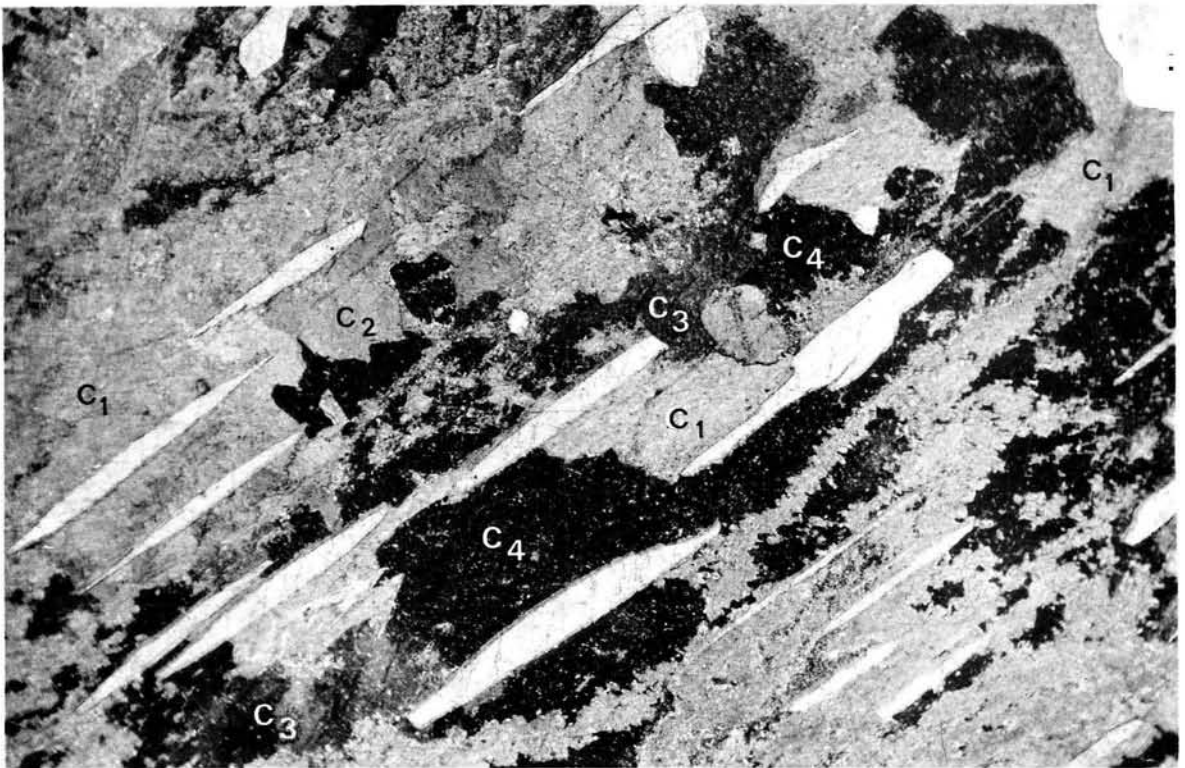
further under petrofabrics. The calcite shows different domains of optical orientation within a single crystal, usually outlined by dust particles, and in addition exhibits a progressive shift of c-axes along a great circle on a stereographic plot.

Parallel growths of dolomite on the (0001) plane of calcite are frequently seen in large metacrysts of calcite in dolomite rock. It is suggested that they do not represent exsolved dolomite but are the products of simultaneous crystallization. The redistribution of graphite flakes on mineral boundaries supports the view that the interstitial calcite fabric is not a result of exsolution. The rare occurrence of spindle-shaped laths of dolomite within calcite may represent exsolution of magnesian calcite present in the dolomitic bands of the calcite marble. The postulate that parallel growth of calcite and dolomite also produces spindles is supported by Plate III, pm 1 where they are shown to be continuous with a dolomite grain. The effect of these dolomite spindles on the pattern of recrystallization of the host calcite crystal is exhibited in Plate III, pm 2.

The dolomite exposed in a quarry on W105 Level (Map 3, HH 165) contains thin intercalations of serpentine derived from forsterite associated with calcite-rich layers up to 2 cm thick. The calcite layers are clearly separated from the serpentine and the amount of calcite is in excess of the amount which could have been generated from siliceous layers

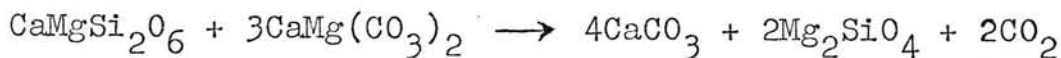


Pm 1. Photomicrograph of parallel growth of calcite and dolomite on the (0001) composition face, exhibiting spindles analogous to so-called exsolution spindles (alizarin-stained calcite, ordinary light, X62).



Pm 2. Photomicrograph showing recrystallized calcite with spindles of dolomite which controlled the configuration of reconstituted domains (C₂, C₃, C₄) in the host. The dolomite remained intact and is parallel to (0001) of the remnant parent calcite (C₁). (Crossed nicols, X52).

by the well-known reactions:-



The repeated occurrence of thin graphitic bands associated with these layers favours the suggestion that we are dealing with primary rhythmic precipitation of siliceous, calcareous and carbonaceous sediments.

The extensive occurrences of dolomite marble on Lot F 0 and at the site of the old Lot F 0 Quarry (Map 1, 15 U 23) are correlated with the dolomite member described above, but have a greater number of aluminous intercalations, as indicated by the development of spinel skarn. A layer of 6 cm width contains the mineral assemblage forsterite-calcite-dolomite-spinel-sphene-phlogopite. Higher in the succession is a 2 cm band of pink spinel with phlogopite. The common occurrence of green streaks in white marble at this locality and elsewhere is due to microscopically thin films of serpentine in transparent forsterite grains. In the quarry striped tufts consisting mainly of phlogopite are present as irregular bodies varying from 10 cm to about one metre in size. They are skarn rocks, in part of metasomatic origin, as well as reworked blocks of amphibolite.

(c) Cluster serpentine marble

The main outcrop of this marble, which varies considerably in composition, is located in the eastern corner of Le Jonquet (Map 3). Towards N'Dongeni this rock type peters out, but to the south patches of it re-appear on Lot F A 3 and East Slopes. In the stratigraphic column of the Le Jonquet Formation (fig. 2) this lithological type is represented by Bed Nos. 4973, 5099 and 5416, which are intercalated with dolomite marble. Bed 5416 forms the major outcrops to the south-east and is present as a single unit on the 199 Level (Map 3, LL 170). The upper layer in this unit consists of fine-grained opicalcite whilst the remainder is made up of quartz-diopside and forsterite-diopside assemblages.

Large nests of serpentinitised calc-silicates and coarse aggregates of diopside with tremolite are typical of the serpentinous marble. They are recognised in the field by their irregular forms in contrast to massive serpentine marble and dolomite marble outcrops. Serpentine clusters of 20 cm in diameter are surrounded by white fine-grained diopside rims. The serpentine varies in colour from grass green through pink to white translucent types identified as antigorite. Other nests or clusters, also rimmed by diopside, consist entirely of tremolite containing up to 10% by volume of coarse flaky graphite. This type of nodular aggregate in association with graphite concentrations is also seen in the lower dolomite marble and probably indicates an original sedimentary feature in the metasediments, as further discussed under Petrogenesis.

(d) Metaquartzite

Du Toit's "quartz-schist" marker is the only stratigraphic horizon indicated on all previous geological maps. The reason is that the outcrops were easy to observe along the chain of hills between the Umzimkulwana and Umzimkulu rivers. Considerable differences of opinion exist concerning the origin of this and other much thinner quartzose bands in the succession. Simpson and Tregidga (1956) preferred "to regard them as sedimentary intercalations of sandstone deposited along with the original limestones" whereas "the technical staff of the marble companies (currently thought) that they are quartz veins genetically connected with the surrounding intrusive granites". These authors also mention the possibility that the main quartzite could have been a cherty zone. In addition there are other types such as quartz-fault breccias, silicified metaquartzite breccias and silicolites with coloured cherty zones. Apart from its structural features, every siliceous rock type in the Marble Delta should be interpreted in terms of its paragenesis reflecting conditions of deposition or metamorphism. For instance, quartz veins from granites have skarn contacts similar to those of the parent granite. Secondary or late quartz has no reaction zones with the country rock.

The interpretation of the main quartzite on top of Umdwendwa Hill as a metasediment by Du Toit (1918) and Simpson and Tregidga (1956) is regarded as correct, but in their further descriptions of this locality quartzitic rock types of diverse origin are confused. Neither the outcrop

of quartz-felspar rock with clastic felspar nor the conglomeratic facies further down the hill, south of East Slopes Quarry, "in which large fragments of white and blue vein quartz are embedded in a highly ferruginised quartzitic matrix" (Simpson and Tregidga 1956, p. 242) and which they interpret as of autoclastic origin, can properly be considered as part of the Marble Delta Group. They are actually infillings of material which originated from the pre-Cape land-surface and should be correlated with the Table Mountain Sandstone, together with sandstone dykes and other irregularities filled by clastic quartz-felspar deposits. As described below, however, an intensely deformed metasedimentary conglomerate which is quite different from the younger conglomerate, does occur in this vicinity.

The main quartzite can be identified in the field by its distinct lineation. Furthermore, the streaky foliation due to the etching out of interleaved white diopside-calcite streaks is conspicuous on a weathered surface, and may resemble schistosity. The main quartzite has been dismembered through mobilization of the marble so that in many places it becomes indistinguishable in the field from the lower or upper and thinner quartzite layers. The blocks have retained the original lineation of the earlier metamorphic period and may plunge in all directions at any particular locality. This is best displayed on top of Lot F N hill and also along the hills of the central Marble Delta from The Glen, Lot F O, East Slopes, Lot F A 3, The Rest and Le Joncquet where the strike of the intermittent

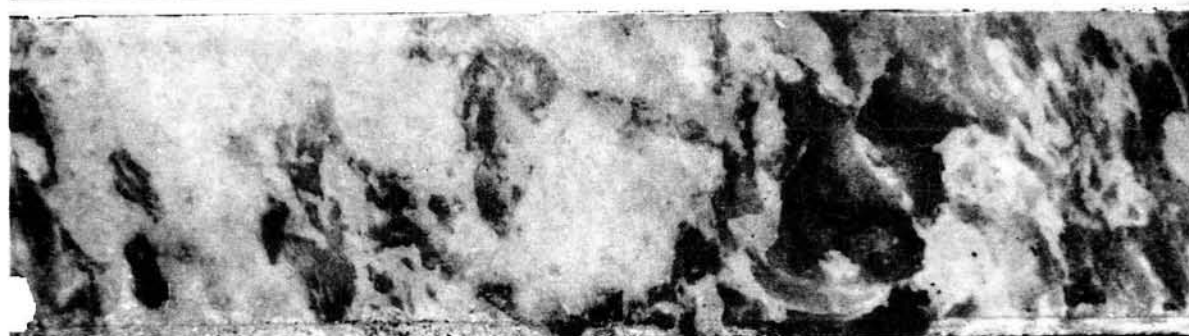
quartzite outcrops swings northwards across the Umzimkulu River on to Westlands. The average thickness of the layer is about 10 metres. Primary sedimentary features are noticeable in the quartzite, which exhibits distinctive patterns similar to those of the upper and lower quartzites (Plate IV). Rare concentric structures of about 10 cm in diameter and consisting of quartz alternating with diopside occur on Westlands; these are probably related to primary features.

A conglomerate occurs in the metaquartzite below East Slopes Quarry towards the bank of the river. The pebbles were flattened and recrystallized to such an extent that only the great number of similar, regularly distributed convex shapes were noticed at first. These are clearly discernible in the matrix since they tend to stand out on etched surfaces. The deformation of this conglomerate is further discussed under Geological Structure.

The quartzites below and above the marker horizon rarely exceed 0,5 m in thickness. One can be traced out in the Horseshoe Cliffs about 110 metres above the Umzimkulu River level. Its layering is a pseudo-bedding probably derived from the deformation of gritty and pebbly material (cf. Geological Structure), and differs from the laminated types which may have consisted of chert only (as compared in Plate IV). The occurrence of conglomerates and gritty quartzites in an environment dominated by chemical or biogenic precipitates suggests rather unusual conditions of deposition.



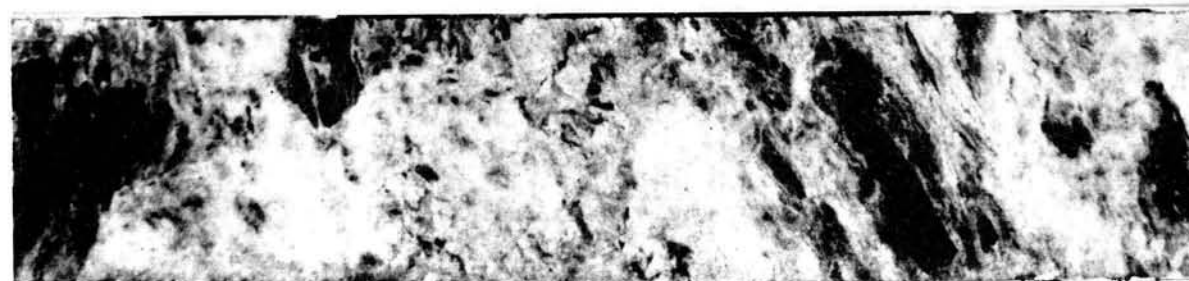
A



B



C



D



E

Variable structure of quartzitic layers in marble representing from A to E Bed Nos. 7839, 8269, 8342, 8565 and 9315 (Fig. 1). White areas are diopside and calcite, black to grey represents quartz. Each bed has structurally different patterns which possibly correspond to original primary features of the metasediment, whether gritty, cherty or laminated (ground surfaces, actual size).

(e) Calcite Marble

The characteristic features of the calcite marbles are their whiteness and very coarse-grained texture. Equidimensional grains of calcite forming a mosaic pattern, show up best on a smooth weathered surface. The pattern is somewhat different in the vicinity of granite intrusions or where there is a change in chemical composition. The average grain size is about 1,5 cm but it is coarser in areas such as 130 Level, (Map 2, H 220) where it averages 5 cm. A notable reduction in grain size is evident from this locality southwards as far as Simuma where it is about 4 mm. The rocks in the eastern Marble Delta are generally fine-grained but become coarser in the Lot F 0 area (Map 1, 14 V) and again finer in a westerly direction towards The Rest. The crystalloblastic fabric changes with the appearance of new mineral assemblages and also along zones of deformation. The change is also reflected in the finer texture and this can be used in the field to identify these rock types, which consist almost wholly of white minerals. The white calc-silicates stand out as pips on a weathered surface.

Inclusions of the calcite marble in granite dykes are finer grained than the calcite wall rock. This reduction in grain size, which is also observed adjacent to certain granites, is indicative of localised recrystallization of calcite compared to the coarse texture of the main calcite marble body, which was subjected to metamorphism of pre-granite age.

Blue calcite bands are associated with wollastonite-bearing beds and large granite dyke intrusions. Streaks of

grey calcite are present in the Oribi Formation, but are especially conspicuous in Bed Nos. 518 and 2338, which are characterized by the smell of H_2S during crushing. The pinkish colour of calcite at the 180 Level (Map 2, W 260) in the Rayon Quarry is due to iron staining in a zone of mild cataclastic deformation of the marble, which was in part replaced by secondary ferruginous dolomite.

Diopside is ubiquitous and not readily recognised by the untrained eye owing to its whiteness. It is, however, present in variable percentages. Diopside becomes slightly greenish in colour when it occurs in impure calcite marble.

Banding is present in the calcite marble in the form of mineral concentrations, and represents the isochemical metamorphic product of original impurities parallel to the bedding. The bands are monomineralic or consist of a combination of two or more minerals, in order of abundance: dolomite, diopside, wollastonite, phlogopite, graphite, forsterite, clinohumite and spinel. Quartz lenses and blebs which represent original bedding are easily distinguished from later quartz introduced by the granites. Some of the lenses are rimmed by a narrow zone of wollastonite and tremolite, which indicates that the reaction was frozen by the build-up of CO_2 . Under similar conditions quartz-calcite formed a stable assemblage and recrystallized into a marble with an equidimensional mosaic of quartz and calcite grains with no wollastonite present (Plate V, pm 1).

The calcite marble as a whole contains approximately 2 - 3% $MgCO_3$, for the most part present as dolomite.

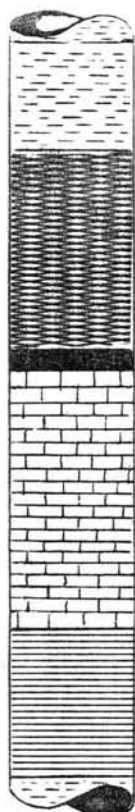
Certain beds with a MgCO_3 content of about 6% have a massive appearance distinct from that of the pure calcite, owing to the presence of subgraphic and rod-shaped intergrowths of dolomite in calcite. These textures are identical with those photographed by Coomáraswámy (1902) in the Ceylon marbles, Russell et al (1955) in the Phalaborwa carbonatite, Goldsmith (1955), Van der Veen (1965) and Carpenter (1967). The textures are regarded by all the authors as representing coherent exsolved dolomite, except that the coarser interstitial dolomite is suggestive of noncoherent exsolution. The intergrowths described above should not be confused with the orientated intergrowths observed in the dolomite marbles. In the latter the simultaneous extinction positions of dolomite in calcite on the (0001) plane indicate parallel crystal growth and not exsolution, as shown by some photographs of the authors mentioned above. The exsolution textures contrast with the subgraphic interstitial calcite in the dolomite marble as well (Plate II). The significance of these textures and the MgCO_3 contents of various Marble Delta calcites are further discussed under Petrogenesis with special reference to the probable temperatures and pressures attained during metamorphism.

(f) Amphibolite

Apart from the extensive amphibolites of the Cherry-willingham Formation, amphibolite also occurs interbedded in the Oribi Formation and in the form of massive sheets and dykes which will be described under Pre-Cape Intrusions. In order to explain these different types of amphibolite, various modes of origin must be taken into account.

The layered amphibolite in the Oribi Formation is regarded as interbedded rather than intrusive, in view of the gradual increase in ferro-magnesian constituents observed in the immediately subjacent marble (Bed Nos. 981 and 1012, fig. 2). The layering in the amphibolite is caused by the variable proportions of dark and light minerals and also by alternation with marble. The paler coloured layers contain a relatively greater concentration of plagioclase and diopside whilst those with a brownish tinge contain more biotite. Individual units vary in thickness from a few mm to several cm. The magnitude of the layering is exemplified by a section at the crusher pit (Map 2, O/P 250) where the thicknesses shown in fig. 3 were noted, starting from a few feet above the base. This section is much thicker than that indicated on the stratigraphic column (fig. 2) further north. The volumetric mode of a typical greyish layer is:-

hornblende	35,8%
clinopyroxene	22,1%
plagioclase	20,9%
biotite	21,2%



- 1,82 m micaceous zone with hornblende
- 3,35 m layered amphibolite
- 0,31 m micaceous layer (biotite) intercalated with hornblende
- 4,27 m calcite marble
- 2,44 m thin bands of pure hornblende in layered amphibolite

Fig. 3. Layering typical of amphibolite in Oribi Formation.

The plagioclase shows occasional normal continuous and discontinuous zoning with the anorthite content decreasing outwards. The composition was determined with the aid of a UM stage and the curves of Burri, Parker and Wenk (1967). The following values were obtained:-

	<u>Core</u>	<u>Mantle</u>	<u>Rim</u>
2V _γ	88°	87°	92°
% An	40	35	29

The fact that the plagioclase is not clouded, and that it retains a normal zonal structure in a metamorphic environment, strongly suggests that a state of disequilibrium was brought about during the waning stage of the last granite intrusion (cf. Chapter IX 3). The biotite is conspicuous for its strong pleochroism:

$\beta = \gamma =$ reddish brown, $\alpha =$ colourless. The pleochroism of

the/

the hornblende is:

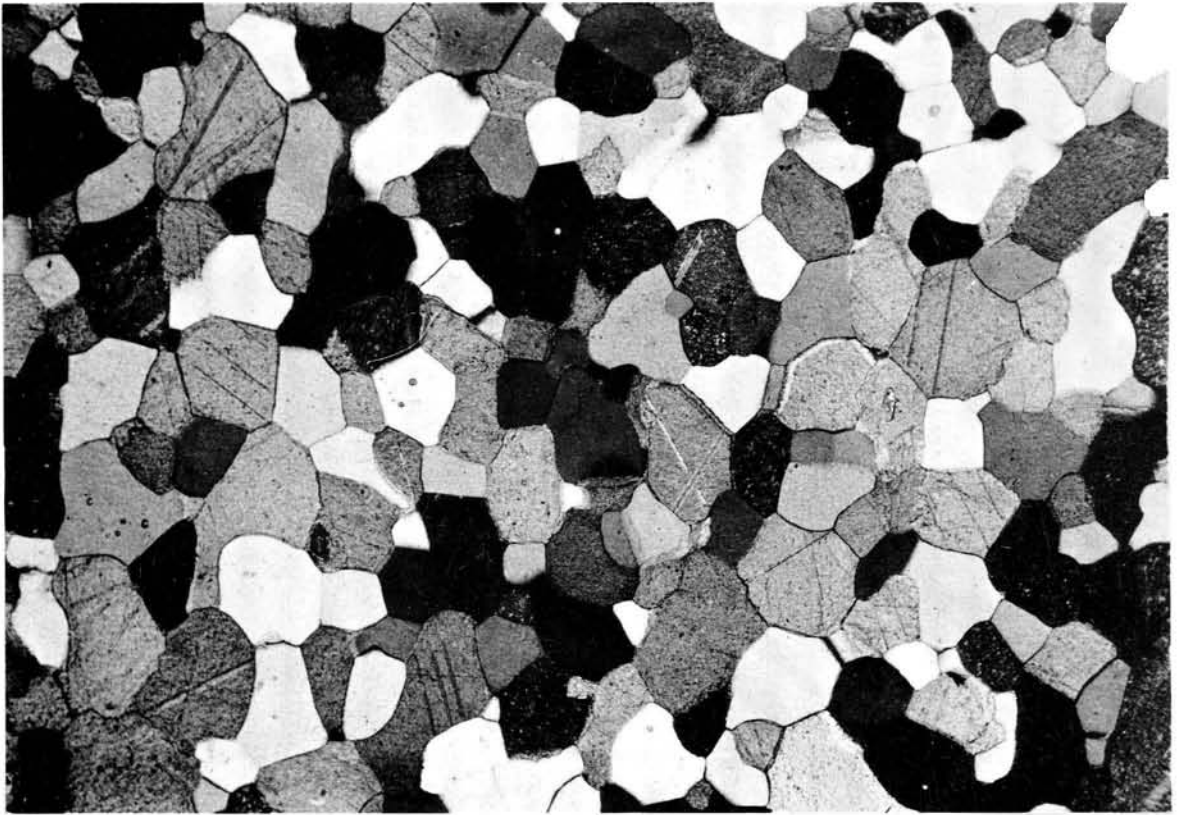
α = pale green, γ = dark green, with optical constants:

$2V_{\alpha} = 81^{\circ}$, $\gamma/c = 18^{\circ}$. Most of the clinopyroxene is slightly greenish diopside while two other dark-green pyroxenes are also sparsely present, which once again indicates that we are dealing with a mineral assemblage in disequilibrium.

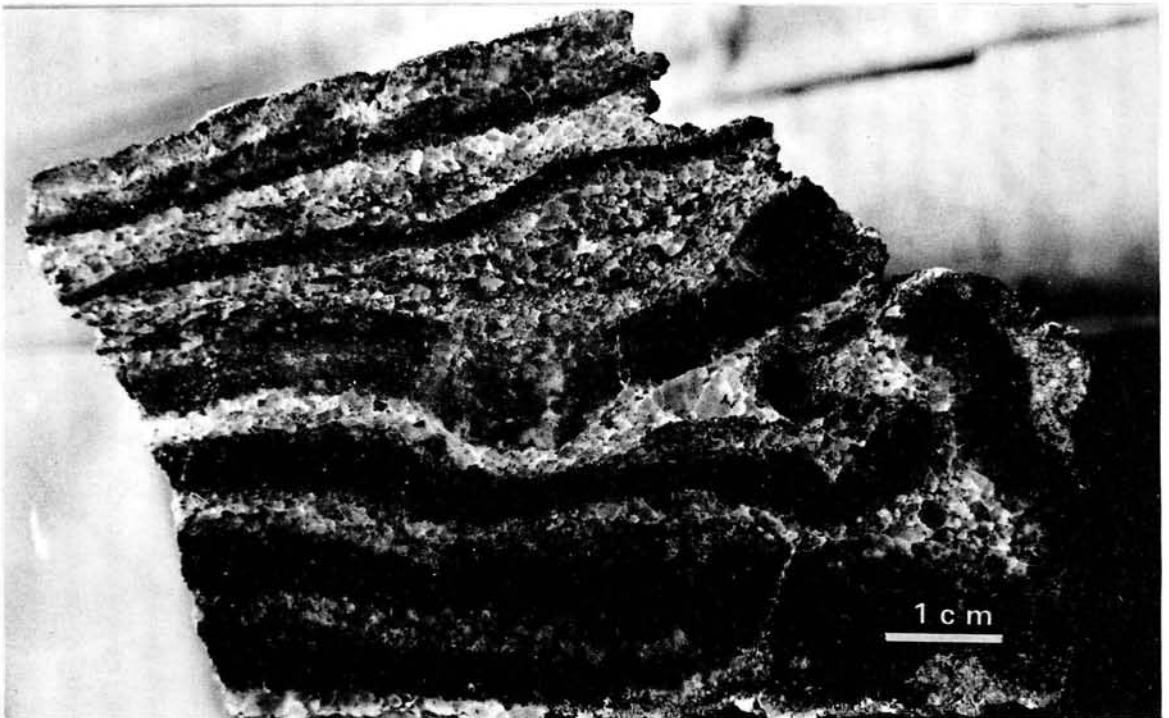
On Lot F 0 and West Slopes amphibolite is exposed along the floodwater tract of the Umzimkulu River. This amphibolite is probably the northern extremity of the tightly infolded syncline on Hebron and The Glen, where it was considered as part of the Cherrywillingham Formation. The banding in the amphibolite is very conspicuous (Plate V, ph 2). Layers of hornblende, about 1 cm in thickness, are intercalated with calcite. The calcite is bordered by green diopside and plagioclase, partly replaced by scapolite, which in turn has been sericitized. The plagioclase grains in the hornblende layers, however, are unaltered relics with the composition of oligoclase (An_{26} , $2V_{\alpha} = 87^{\circ}$). The hornblende is brownish green (β) and dark green (α) with $2V_{\alpha} = 78^{\circ}$ and $\gamma/c = 15^{\circ} - 16^{\circ}$.

Further downstream is a band of black and more coarse-grained (0,4 cm) hornblendite, 0,7 metres in thickness. The rock contains 90% hornblende and 8% hypersthene by volume, with the remaining 2% consisting of interstitial plagioclase, quartz and biotite. The hornblende is pale green to brownish in thin section ($2V_{\alpha} = 72^{\circ} - 87^{\circ}$, $\gamma/c = 14^{\circ} - 21^{\circ}$). The hypersthene is colourless to slightly grey in thin section with $2V_{\alpha} = 60^{\circ} - 66^{\circ}$ and is concentrated as screens

which/



Pm 1. Photomicrograph showing equidimensional granoblastic texture of quartz-calcite marble from East Slopes with no wollastonite present (alizarin-stained, crossed nicols, X55).



Ph 2. Photograph of banded amphibolite showing contorted layers of hornblende intercalated with calcite and bordered by scapolite and plagioclase.

which may represent original bedding. The hypersthene as well as the hornblende shows marked preferred orientation which probably indicates crystallization under conditions of the same metamorphic facies.

(g) Clinopyroxene-calcite marble

The clinopyroxene-calcite marble occurs in the north-western corner of Le Jonquet, and has a wide distribution to the north across the Umzimkulu River on to N'Dongeni, where massive outcrops form part of the cliffs. It is characterized in the field by the presence of hornblende-pyroxene porphyroblasts.

At E/F 215 on Le Jonquet the clinopyroxene-calcite marble forms a sharp contact against the calcite marble. This is probably a tectonic contact, since there is evidence of deformation and secondary alteration of the rock, but further west (Map 2, E 227) a tongue-like outcrop of the clinopyroxene-calcite marble projects across the calcite marble. This protrusion is on strike with, and directly opposite the dismembered blocks of a layered amphibolite (fig. 2, Bed 597).

Prominent banding is displayed in outcrops along the Umzimkulu River banks. Flow structures with different sizes of porphyroblasts, some of which are perfectly terminated crystals, are not derived from the original stratification. In this case the layering is not due to metamorphic differentiation in the strict sense, but a result of flow banding after the dissociation and recrystallization of

amphibolite/

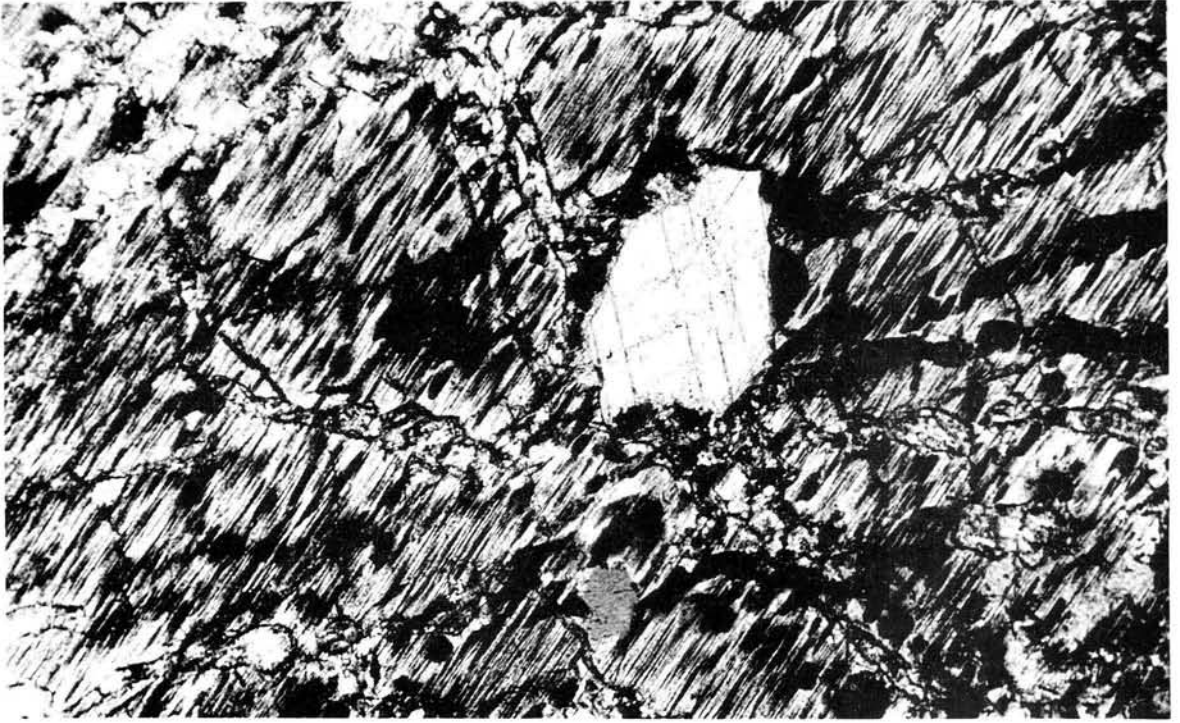
amphibolite material.

The euhedral to subhedral porphyroblasts vary from a few millimetres to about 3 cm in diameter. In the outcrops exposed in the Umzimkulu River these porphyroblasts attain a size of 18 cm. They are usually composite porphyroblasts with hornblende clearly replacing an augitic pyroxene. Fine lamellar twinning in the pyroxene is also associated with thin spindles of hornblende, together with rod-like forms, which are analogous to exsolution textures (Plate VI, pm 1 - 2).

The metacrysts of pyroxene contain bunches of pyrite of similar grain size as the poikilitic texture of the porphyroblasts. This suggests that the pyrite was introduced at the time of recrystallization. Pyrite also coats the porphyroblasts and occurs as intergranular grains. It is concluded that pyrite was introduced throughout the recrystallization period (Plate VI, pm 2).

The origin of this marble can be best understood if it is postulated that it resulted from the disintegration of the amphibolite during the mobilization of the marble. The dark minerals recrystallized as euhedral hornblende-pyroxene porphyroblasts. The numerous and varied inclusions in the porphyroblasts, and the fact that the blocks of amphibolite contain relics of its former fine-grained texture, indicate that this mobilization took place after the regional metamorphism. Numerous minor intrusions of Buffalo Bill granite cut across the clinopyroxene marble and are therefore later. It is therefore suggested that a nearby basic

intrusion/



Pm 1. Photomicrograph of clinopyroxene porphyroblast in calcite marble showing twin lamellae with parallel growths of hornblende which are also in optical continuity with hornblende present in the radiating strain pattern around a calcite inclusion. Top left and bottom right-hand portions of porphyroblast are clear and untwinned (crossed nicols, X76).



Pm 2. Photomicrograph of a clinopyroxene porphyroblast with rod-like blebs of hornblende (Ho) at right angles to c-axis of host yet in optical continuity with hornblende films along constricted clinopyroxene twin lamellae. Pyrite (Py) which replaces hornblende also occurs euhedrally on grain boundary with calcite (Cc). (Crossed nicols, X72)

intrusion caused the mobilization of the marble and that in situ sulphur was at the same time obtained and possibly reworked from the grey limestone.

(h) Granulites

The term granulite is used in the sense of Rice (1960), for "A granulose metamorphic rock composed of even-sized interlocking granular minerals. Parallel or banded structure is due to either the presence of streaks and lenticles of non-granular quartz, or to the alternation of bands in which different minerals predominate = leptynite". The granulites described below do not represent the granulite facies of metamorphism. The term fels is used to describe any specific type of granulite in accordance with the suggestion by Winkler (1967) that "fels" should be used instead of "rock" for "massive metamorphic rocks lacking schistosity, e.g. calcsilicate fels".

All the layered granulites, including those not directly associated with the amphibolites, have been grouped with the Cherrywillingham Formation. Only a few exposures are available in the Marble Delta area. The more conspicuous lithological types in terms of their mineral assemblages are as follows:

1. biotite-ilmenite-plagioclase-cordierite-garnet-quartz-fels
2. graphite-biotite-plagioclase-quartz-fels
3. graphite-felspar-clinopyroxene-quartz-fels
4. ilmenite-biotite-garnet-felspar-quartz-fels
5. sericitized felspar-hornblende-clinopyroxene-fels

6. sphene-clinoamphibole-clinopyroxene-bytownite-fels
7. graphite-biotite-plagioclase-quartz-fels
8. clinoamphibole-sphene-clinopyroxene-plagioclase-fels
9. sphene-clinoamphibole-grossularite-clinopyroxene-plagioclase-fels

The first three granulite types occur on the northern side of N'Dongeni as isolated outcrops, close to the contact of the St. Faith's granite. These exposures are just north of the last outcrops of the Oribi Formation. They are therefore tentatively correlated with the Cherrywillingham Formation which contains similar beds in the eastern part of the Marble Delta.

The cordierite-garnet-fels is dark to bluish in colour with reddish pink porphyroblasts of garnet (1 - 2 mm) in a matrix (0,4 mm) of quartz and cordierite. The volumetric mode is:

quartz	34,3%
cordierite	34,0%
garnet	18,0%
plagioclase	9,7%
biotite	2,4%
ilmenite	1,6%

Microscopically the garnets show resorbed outlines, especially against quartz and are studded with inclusions of quartz, plagioclase and ilmenite. The garnet is almandine-rich, as determined by the unit cell parameter ($a = 11.56\overset{\circ}{\text{\AA}}$), refractive index greater than 1,81 and relatively high density. The cordierite is colourless and clear except for an

occasional/

occasional pinitized streak, and is slightly coarser in grain than the quartz. X-ray diffractograms show separation of the (110) peaks and the mineral is, therefore, a low cordierite. The ilmenite grains are usually round with an occasional crystal face. The unit cell parameters were found to be $c = 14,09\overset{\circ}{\text{\AA}}$ and $a = 5,08\overset{\circ}{\text{\AA}}$. When this is compared with other ilmenites (Deer et al, 1962) the mineral appears to have a relatively small cell volume, which may be related either to the ilmenite-hematite series, or to order-disorder transformations .

Immediately to the south of the cordierite-garnet-fels there is an outcrop of exceedingly fine-grained rock with an average grain size of 0,29 mm. It is a graphitic biotite-plagioclase-fels. The volumetric modal analysis of this rock shows that it contains:

quartz	66,9%
plagioclase	16,5%
biotite	11,9%
graphite	4,1%
pyrite	0,6%

The biotite and graphite flakes show parallel orientation in a lepidoblastic texture. The fine texture of this rock in contrast with adjacent granulites, may perhaps be ascribed to the inhibiting effect of the graphite on the recrystallization. A buffering action by graphite may also depress the oxygen fugacity to such an extent that it will influence the stability of minerals that would normally co-exist with a fluid phase and high f_{O_2} .

On the farm Hebron a layer of garnetiferous rock a few metres wide overlies the amphibolite and is associated with greyish black calcite and calc-silicate bands. This garnet gneiss is distinct from the garnetiferous granite (The Wolds granite) which intruded these rocks. The garnet gneiss is thinly laminated and contains ilmenite which is partly altered to a white material, probably leucoxene.

On Cherrywillingham Park a number of pyroxene-plagioclase-quartz-felses with an average grain size of 0,4 mm are found. Sphene is the prominent titanium mineral instead of ilmenite as in the west. Certain layers also contain 1 cm wide yellowish-pink laminations consisting of grossular garnet ($a = 11,84\overset{0}{A}$). This garnet, which is usually free of inclusions, indicates the presence of original calcareous material. The variation in mineral composition from one zone to another, is given as volumetric modes:

	<u>A</u>	<u>B</u>	<u>C</u>
Plagioclase	54,5	44,5	47,1
Clinopyroxene	0,0	50,6	38,2
Quartz	31,2	0,0	0,0
Biotite	6,7	0,0	0,0
Grossularite	0,0	0,0	12,4
Graphite	7,6	0,0	0,0
Sphene	0,0	4,9	2,3

According to CIPW norm calculation from the modal analyses the rocks fall in the metagabbro class.

3. MINERALOGY

The minerals are described in approximate order of abundance.

(a) Calcite

The exceptional whiteness of the calcite in the marbles of the Oribi Formation on Le Joncquet and The Glen is one of the main reasons for its industrial use. The reflectivity of certain calcite powder products is comparable to that of TiO_2 powder, yet each individual grain is transparent under the microscope. Since clear or optical calcite produces a "grey" powder, this property requires some explanation. Detailed studies may perhaps reveal the presence of structural imperfections or submicroscopic particles.

In addition to white calcite, blue, greyish black, yellowish, greenish, pinkish and reddish calcite are also known in the area. The diversely coloured varieties of calcite as seen in the field can be shown to be related to different periods of crystallization as well as the composition of the rock. In the dolomite and calc-silicate marbles the thin intercalated calcite or calcite beds are seldom coloured. Blue calcite is associated with disseminated wollastonite in marble and with granite dykes greater than 1 metre in width. Zones of coarse, blue calcite were formed next to constricted granite bodies and contorted granite dykes. A border zone of blue calcite separated from the dyke by grey calcite may follow the configuration of a dyke contact. The maximum development of blue calcite

in the Marble Delta is on Le Joncquet (Map 2, N 235).

Greyish black calcite is present on N'Dongeni as crystals up to 60 cm in diameter, and was formed in metamorphosed impure sediments along with varying percentages of graphite and clinopyroxene. The dark shade is due to unidentified minute black rounded particles and crystallites, ranging from 0,1 micron to one micron in diameter. Other grey calcite zones (cf. fig. 2) and irregular patches owe their origin to the redistribution of particles in grey calcite bands during the recrystallization caused by the dyke intrusions of the Buffalo Bill granite.

Yellow to olive-green or greenish calcite is related to the late phase introduction of granitic dykelets (2 - 5 mm in width), emanating from a parent body. Where such a dykelet intersected amphibolite rafts, a yellowish calcite cuts across the blue calcite. Pinkish to reddish calcite is associated with subsequent deformation zones of pre-Cape age. Greyish to transparent calcite is present in the younger red dolomite replacement bodies and also in post-Karoo calcite veins. It is therefore possible to recognise different calcite parageneses in the field by colour only.

Lamellar twinning of calcite on $(01\bar{1}2)$ is commonly observed throughout the marbles. The origin of the lamellar twinning has been studied in great detail in the past. It has been shown that glide twins can be produced artificially by mechanical deformation of calcite even during thin section preparation. The occurrence of lamellae was studied

along/

along a dolerite contact against marble at the Rayon Quarry (Map 2, W 255) where it was found that during intrusion, calcite had been partly dislodged from the wallrock and twins had been sheared, whilst flexured and broken lamellae were found to match across fractures. This proves that at least some of the lamellar twinning originated before the intrusion of dolerite, probably during the pre-Cape deformation of the cataclastic zone at the Rayon Quarry or during the last metamorphic period.

The amount of MgCO_3 retained in solid solution by calcite could be of petrogenetic significance. Therefore four varieties were selected for X-ray diffraction: blue calcite near the contact of a granite dyke, a large white calcite grain (12 cm) from site I 217 (Map 2), black calcite from N'Dongeni and interstitial calcite from the Dolomite Quarry (W 105 Level). The results were compared with the compositional variation diagrams of Chave (1952) and Goldsmith et al (1955) for the (112), $(11\bar{2})$, (444), (521) and (663, 552) reflections. This exercise showed that all the samples had a very low MgCO_3 content, to the amount of about one per cent and less. The highest values were obtained on the black calcite and the interstitial calcite.

Intergrowths of dolomite in calcite are described under Calcite Marble and further discussed under Petrogenesis.

(b) Dolomite

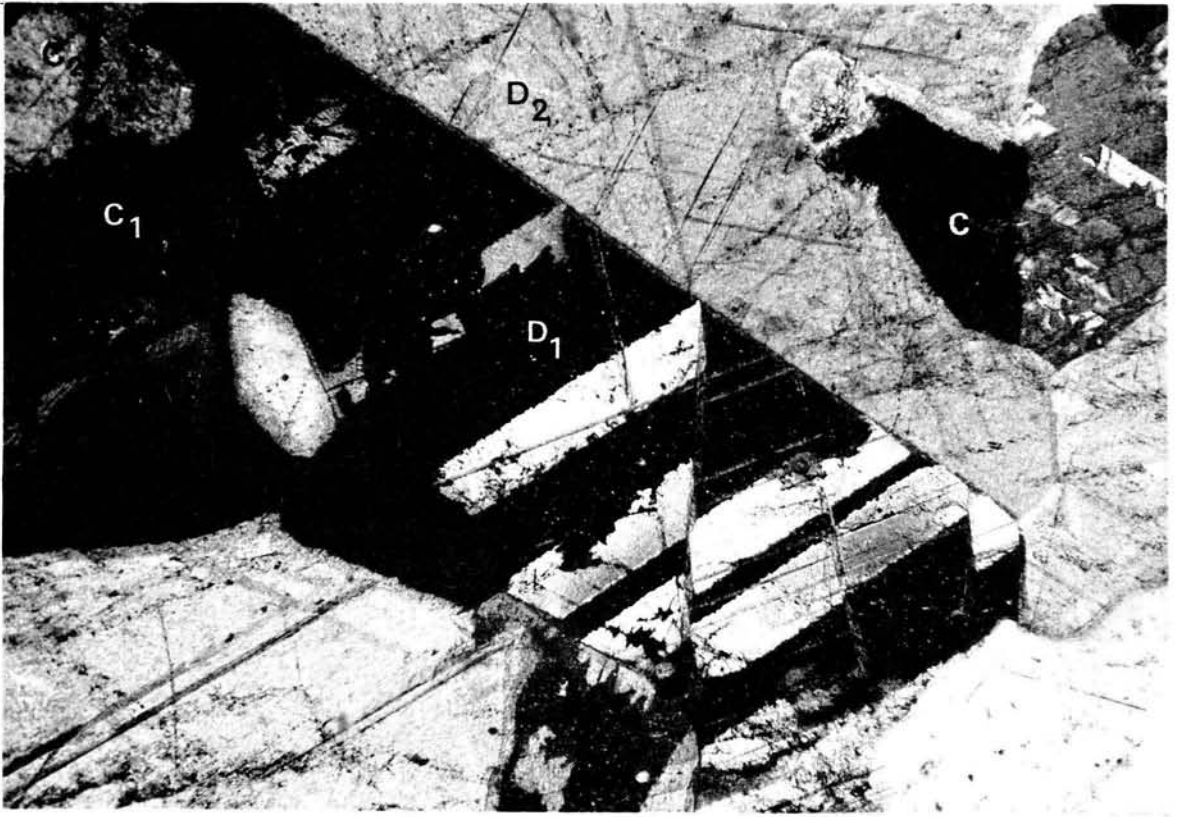
Milky white dolomite which forms part of the Oribi and Le Joncquet Formations occurs throughout the Marble Delta. Dolomite bodies genetically unrelated to the marble are coloured chocolate brown to brownish red; they replace both calcite and dolomite marble. The grain size of the metamorphic dolomite is controlled by the last period of recrystallization and is always slightly smaller than that of the co-existing calcite layers nearby.

The lamellar twinning in dolomite is often found to be discontinuous, especially where a second or third stage of recrystallization of the calcite has taken place. It is possible that the interrupted lamellae may represent an intersection of a differently orientated second translation glide which reverses the structure of the dolomite at the intersection. But they are so irregular in shape that the discontinuity should rather be attributed to partial recrystallization. An offset of lamellae in this case dates some of the lamellae; they must have formed prior to the last granite intrusion, which caused the recrystallisation of the interstitial calcite under P-T conditions which did not affect the dolomite to the same extent. (Plate VII, pm 1 - 2).

(c) Diopside and other pyroxenes

The fact that white diopside is not readily discernible in the dolomite marble, is probably the reason why it was never reported to occur in the old quarries. On a weathered surface these large white diopside crystals are easily

mistaken/



Pm 1. Photomicrograph showing twinned dolomite (D_1) which has been offset before recrystallization (D_2). Note the irregular form of the lamellae and their discontinuity due to partial recrystallization (alizarin-stained, crossed nicols, X55).



Pm 2. Photomicrograph showing a dolomite grain which was first twinned and then resorbed (four patches in optical continuity). Lamellar twinning and deformation have taken place prior to resorption and recrystallization of calcite in forsterite-dolomite-calcite-marble. (Alizarin-stained, crossed nicols, X55).

mistaken for wollastonite or tremolite bunches. The diopside occurs as euhedral crystals up to 20 cm in length with perfectly developed (101), (110), (010) and (100) faces, especially in the dolomite marble in the Lot F 0 area. In the western part of the Marble Delta the diopside is usually finer grained and is distinguished from forsterite by the lack of a green or yellowish tint arising from the serpentization of the forsterite. At site BB 218 on Le Joncquet the dolomite marble contains exceptional clusters (35 cm) of coarse diopside (1,5 cm) surrounded by a rim of serpentine. Diopside in which Fe^{2+} substitutes for Mg in the structure has a slightly greenish tint. Pyroxene of the more iron-rich salite-hedenbergite series is present in the impure metasediments of the N'Dongeni area and in various skarn rocks. These dark green clinopyroxenes are clearly distinguishable in the field from the coccolite type developed on the contacts of granite bodies in calcite marble. Orthopyroxene was encountered in an amphibolite of the Cherrywillingham Formation.

On Lot F 0 and Lot F N, 5 cm veins are present which consist wholly of white diopside. These were introduced after the main period of deformation (F_1) that affected the quartzites.

(d) Forsterite

Forsterite occurs throughout the Marble Delta and is specifically developed along granite-skarn contacts in the dolomite marble and siliceous dolomite marble of the Le

Joncquet/

Joncquet Formation. No large crystals comparable to those of the other metamorphic minerals were found. The size of the round grains of forsterite in the lower part of the Le Joncquet Formation averages 0,2 mm. Coarser forsterite up to a few millimetres in size was once present in the upper part of this formation as can be deduced from the serpentine pseudomorphs. The serpentine contains unaltered relics of forsterite ($2V_{\gamma} = 87^{\circ}$), and is clear without any trace of ferruginous material.

(e) Serpentine

Serpentine commonly occurs in the upper marble of the Le Joncquet Formation as transparent to white nodular (10 cm) concentrations, and appears on a weathered surface as white patches. The greatest development is in the central part of the Marble Delta on Le Joncquet. It is usually antigorite. Crysothile veinlets traverse these clusters of serpentine in the massive marble. Olive-green serpentine is usually concentrated near granite contacts, especially in the Lot F 0 area, where it evidently represents a late phase deuteric alteration caused by the granite intrusion (cf. Plate XVI, ph 1). The alteration along the contact may be traced into a normal skarn contact of granite against marble. Pink serpentine occurs as isolated bodies (0,5 m) in the dolomite marble (Map 3, 76 Level, FF 160) and also as veins in the marble units on Lot F 0 and Lot F N. Analysis of white serpentine on Lot F 0 gave: SiO_2 42,4; Al_2O_3 0,6; CaO 1,0; MgO 41,1; Loss Ign. 14,8 per cent.

(f) Wollastonite

Wollastonite occurs extensively in the Marble Delta. On Le Joncquet it forms aligned friable bundles in the calcite marble (site H 215). The bundles plunge 45° to the south-west, forming a lineation in the marble which was established before the intrusion of the granite. This particular zone is also associated with bluish calcite. Large concentrations of wollastonite are also present on Lot F 0 and East Slopes where it forms a prominent band of tough, rosette-like wollastonite rock unlike the usual friable type. Elsewhere in the Marble Delta wollastonite is occasionally associated with serpentine-diopside clusters and locally with dykelets of intrusive granite.

Wollastonite commonly forms a narrow (3 cm) rim bordering quartzite beds. In the thinner intercalated siliceous zones (e.g. Bed 1219), characterized by a greater reaction surface area allowing also a greater permeability for the expulsion of CO_2 , the formation of wollastonite was possible during each successive metamorphic period. Consequently all the available SiO_2 was used up to form a wollastonite-diopside assemblage arranged in bundles while adjacent dislocated quartzite blocks remained unaffected. With increasing temperature and pressure during metamorphism, the marble underwent recrystallization with incipient flowage, thus preventing the escape of CO_2 along the calcite-quartz interface. Under these circumstances quartz-calcite and/or dolomite would become stable phases, and no further wollastonite or diopside would crystallize owing to the high P_{CO_2} .

(g) Tremolite

Tremolite varies in colour from transparent to white, pale green or pale brown. The mineral is recognised in the field by the development of (110) faces producing long bladed crystals which are occasionally terminated by (011) faces. Large greyish crystals (10 cm in diameter) are found in the Lynwood Quarries (Map 1, 5 V). Tremolite occurs throughout the Marble Delta but there is no significant concentration at any specific locality. Conspicuous, however, are large clusters (15 - 20 cm) in the dolomite marble (Map 3, W 105 Level). The clusters of reticulated tremolite crystals (1 x 5 cm) often contain interstitial calcite or graphite flakes, and may have a rim of white diopside and/or serpentine. Colouration of the tremolite due to substitution of Mg by Fe^{2+} is found in impure marble zones or where an amphibolite was recrystallized during the last period of contact metamorphism. The d-spacings of three specimens show a serial variation of the (510) reflection corresponding to their variation in colour.

(h) Phlogopite

This mineral occurs mainly in reworked amphibolite, contact skarn and layers of impure marble. Single euhedral crystals or aggregates of phlogopite range from colourless to white, yellow and brown, depending on the skarn association and relative availability of Fe^{2+} . White or transparent phlogopite occurs predominantly in the dolomite marbles in association with contact zones of granite dykes.

Gower (1957) found that the intensity ratios of (004)/(005) reflections show a correlation with the percentage iron in the octahedral sites. Four micas were therefore collected from 1) a scapolite skarn, 2) a broad skarn contact near granite, Lot F 0, 3) massive phlogopite skarn near granite, 4) Spitzkoppie granite, S.W.A. The intensity was measured by taking continuous counts between fixed pre-determined 2θ angles at a slow scanning speed of $1/8^\circ$ $2\theta/\text{min}$. The approximate Fe contents in the octahedral sites according to Gower's curve were found to correspond with the colour variation in the phlogopites, as follows:

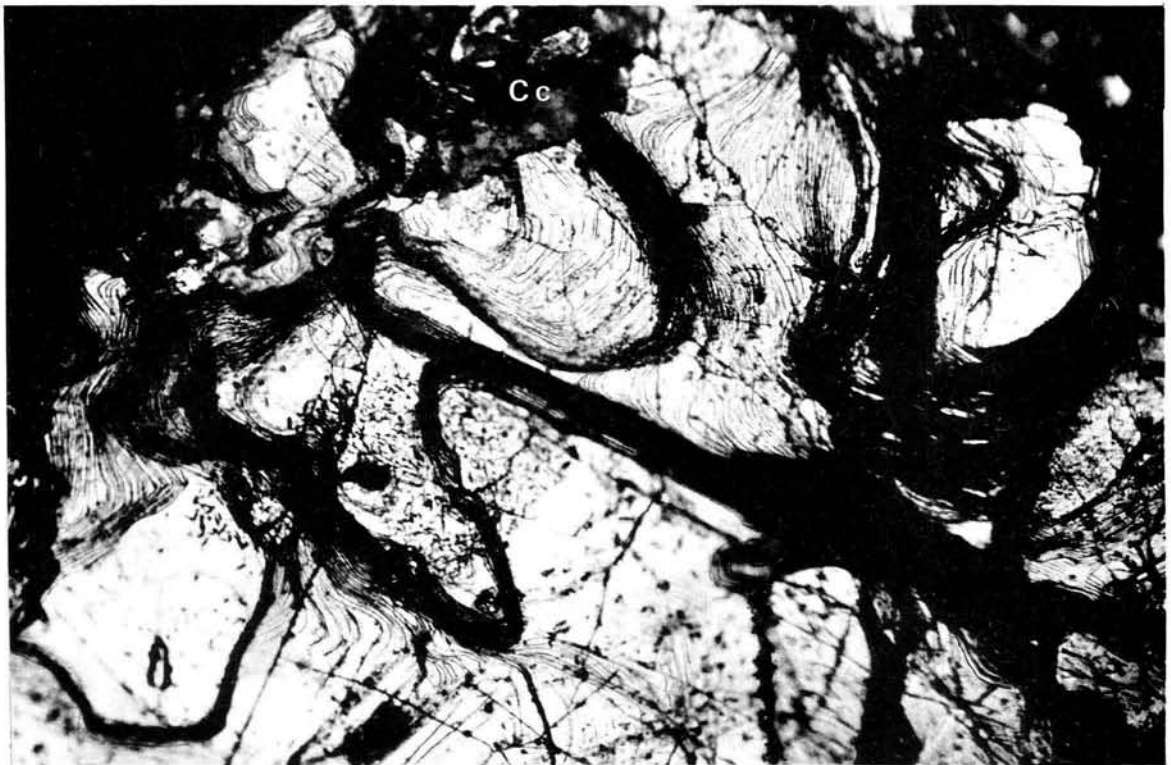
	1	2	3	4
	pale brown	reddish brown	dark reddish	dark green
$I_{\text{obs}}(004)/I_{\text{obs}}(005)$	0,33	0,39	0,47	1,046
% Fe in oct. sites	4	10	17	64

Subsequent metamorphism affecting amphibolite blocks in dolomite marble caused phlogopite skarn to develop at the interface of marble and amphibolite. Such reaction may cause replacement of the entire amphibolite dykelet by phlogopite (Plate VIII, ph 1). The effects of this reaction are rarely seen in the calcite marble. Granite contact skarns also show greater development of phlogopite with dolomite as wall rock. This phlogopite is distinguishable in the field from phlogopite thought to be derived from originally potash-bearing metasediments. The isochemically produced phlogopite is evenly disseminated, fine-grained, and may locally form definite bands in the phlogopite-calcite marble. A 7 cm

thick/

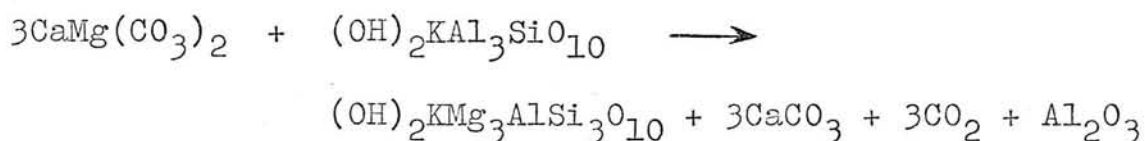


Ph 1. Amphibolite dykelet in calcite-dolomite marble. The unaltered core of amphibolite is surrounded by phlogopite which forms part of an induced contact metamorphic skarn (ground surface).



Pm 2. Corroded hollows formed by metamorphic etching of octahedral face of spinel. Calcite was mechanically removed and terraced structure brought out by viewing in reflected light at critical angle, X26.

thick layer (Map 2, J 215) consisting almost wholly of pale phlogopite possibly represents a potash-rich bed comparable to the phlogopite-cummingtonite-microcline layer a few metres lower down in the succession. These phlogopite layers were broken up during the last mobilization of the calcite which shows that there must have been an earlier metamorphic episode. Similar metasedimentary layers (6 cm thick) with a phlogopite-spinel assemblage are present on Lot F 0 in the dolomite marble. Yoder (1954) suggested that phlogopite could have originated from muscovite (=illite) and dolomite. Such a reaction would explain the excess alumina necessary for the formation of spinel which is usually present only in other highly aluminous bands in the Marble Delta:



The formation of phlogopite by this mechanism depends to a large extent on the P_{CO_2} which, by depressing the oxygen fugacity, must affect the iron buffer, and thus determines the colour of the phlogopite. Furthermore, high $P_{\text{H}_2\text{O}}$ may be the reason why phlogopite is usually formed on the inside of a contact skarn mineral assemblage as well as on the inside of an amphibolite reaction zone against dolomite. In these cases phlogopite crystallizes together with the calcite produced by the reaction.

(i) Graphite

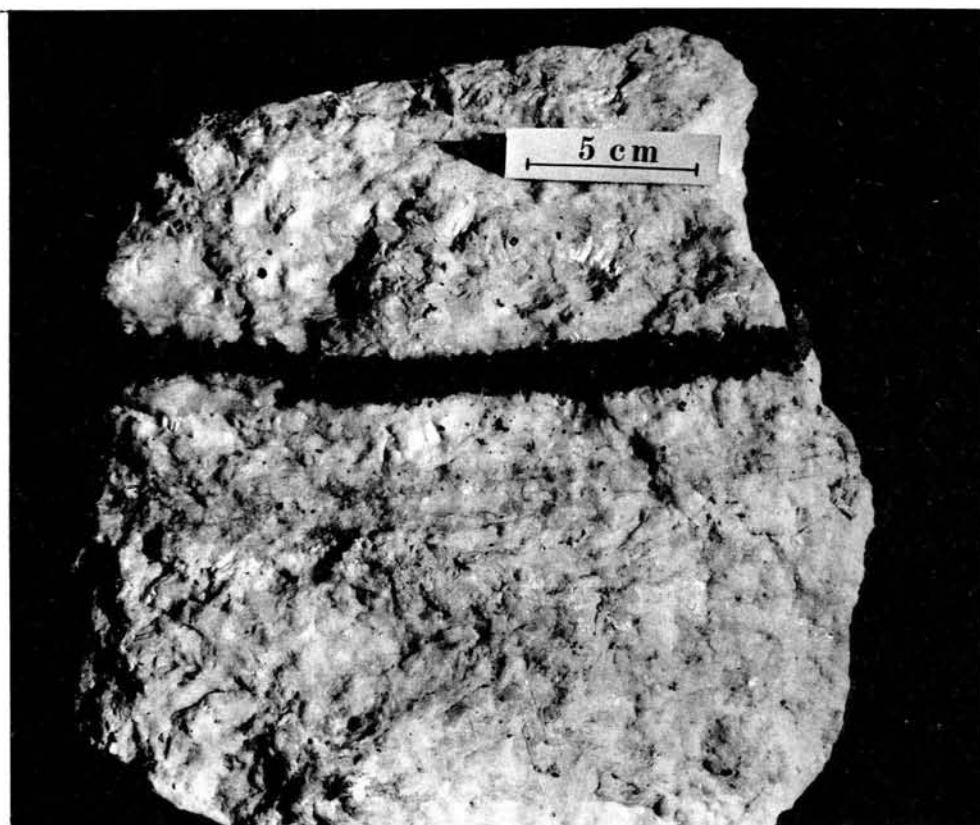
Stratigraphically the first noticeable appearance of graphite is in the upper part of the Le Joncquet Formation. Higher up in the succession graphite becomes more conspicuous and forms distinct layers a few cm thick in the lower Oribi Formation. Graphite also occurs as patches several metres wide in the clinopyroxene-calcite marble, probably due to extensive mobilization of the marble and associated hornblende concentrations. These enriched patches led prospectors to drive trenches and adits into the hills in search of graphite deposits.

The general mode of occurrence of graphite in the Marble Delta is:

- 1) As graphite layers, 1 - 4 cm thick (Plate IX, ph 2)
- 2) As disseminated graphite flakes:
 - (a) in graphitic marble units
 - (b) evenly distributed in the marbles
 - (c) in graphitic concentrations due to mobilization
- 3) As flakes in metaquartzite
- 4) As flakes in granulites and amphibolite
- 5) Concentrated as clusters in calc-silicate skarn and amphibolite dykes
- 6) As flakes in peripheral granites and gneiss
- 7) As concentrations of flakes on borders of contact skarn mineral assemblages
- 8) In pneumatolytic veinlets
- 9) Along borders of quartz veinlets emanating from granite and cutting across the layering of graphite-free marble.



Pm 1. Hexagonal flake of graphite showing no adaptation to reticulated fabric of surrounding tremolite rock. Note the striations intersecting at 60° on the (0001) plane of graphite. (X22).



Ph 2. Calcite marble with graphite layer parallel to faint calc-silicate streaks representing relic bedding. Scattered graphite flakes are present

(This granite intrudes graphitic concentrations mentioned under 2(c) above).

The size of the graphite flakes varies sympathetically with the grain of the calcite and dolomite marble or metaquartzite. Graphite occurs as subhedral plates in friable marble and as hexagonal plates in tremolite rock, in which case it frequently shows striations intersecting at 60° (Plate IX, pm 1). Detached metaquartzite bands, a few cm thick, contain minute scales of graphite which are concentrated and coarsely crystalline on the outer surface but absent wherever a thin veneer of wollastonite is present.

As discussed under Petrogenesis, the graphite is considered to be derived from carbonaceous matter and not from carbonates.

(j) Clinohumite

Of the humite group of minerals, clinohumite commonly occurs throughout the Marble Delta, and not chondrodite as described by Du Toit((1919). Chondrodite is rarely found except in contact skarn. The clinohumite occurrences are controlled by the relict bedding of the marble. Colours in the field range from a very pale yellow to honey yellow and reddish brown to chocolate brown. The reddish brown clinohumite occurs on N'Dongeni and is associated with calcite layers with a high dolomite content, whilst the yellow clinohumite on Le Joncquet appears in dolomite marble and calcite marble. A volumetric mode of a brown clinohumite

marble on N'Dongeni is as follows:

calcite	62,3%
clinohumite	19,5%
dolomite	10,6%
diopside	5,0%
spinel	2,2%
graphite	0,4%

Clinohumite was found to replace white phlogopite in certain zones of this marble.

Isolated crystals of clinohumite attain a size of 5 cm in the dolomite marble in the middle of the Le Joncquet Formation. The clinohumite shows alteration to poorly crystalline serpentine (strongest X-ray line, $d = 6,95\text{\AA}$) and is usually accompanied by isolated crystals of clear diopside in the dolomite marble.

Variation in $2V_\gamma$ ($76^\circ - 70^\circ$) may be due to $\text{Fe}^{2+} - \text{Mg}$ substitution and the exchange of F and OH. The only variation noticed in X-ray diffractograms is a shift of the (210) reflection. No relationship was found between the variations in properties of clinohumite and calcite or dolomite as host rock.

(k) Spinel

Several varieties showing a wide range of colours are present in the Marble Delta. Ruby-red to pale pink spinel commonly occurs in the form of scattered octahedral crystals along bedding traces of the calcite and dolomite marble, and may represent a thin, original intercalation of a highly

aluminous/

aluminous sediment. Dark to pale mauve spinel is associated with forsterite, sphene and serpentine and represents originally pelitic layers. A green spinel occurs in the clinohumite marble on N'Dongeni. Hercynite (dark green in thin section) is found on Le Joncquet together with ilmenite whilst purple tinged spinel crystals (2 cm in diameter) appear in the calcite marble in association with phlogopite. Occasional ice-blue spinel occurs in phlogopite-calcite marble beds e.g. Bed No. 981 (fig. 2). The blue spinels contain Fe^{2+} and brown varieties have Fe^{3+} according to Schlossmacher and Meyer, so that the intermediate shades of purplish to violet mentioned above could be due to mixtures of these ions (Deer et al 1962). The cell parameters of two spinels were calculated from X-ray diffraction photographs and are as follows:

Lot F 0, pink spinel	$a = 8,09\overset{\circ}{\text{\AA}}$
Le Joncquet, Mg-hercynite	$a = 8,11\overset{\circ}{\text{\AA}}$

Spinel in the calcite marble shows resorption embayments which have contoured, stepped surfaces similar to etch-figures on crystal faces (Plate VIII, pm 2).

(1) Scapolite

Scapolite occurs throughout the Marble Delta in skarns but is also concentrated as isolated veins at skarn contacts or in structural dislocations in amphibolite, and in the form of remarkable monomineralic dykelets. It is furthermore found disseminated along the layering and in clusters in dolomite but is not considered to be due to scapolitization

during/

during regional metamorphism of the marble. Most of the scapolites are within the mizzonite range (Mei 50 - 80) of the solid solution series, although they show a wide variation in colour. On Le Joncquet the scapolite is definitely related to the last stage of granite dyke intrusions.

X-ray diffractometry has shown that the composition (meionite content) depends to some extent on the distance from a granitic parent. The more sodic scapolites (fig. 6 A) are possibly linked with the basic igneous intrusions and soda-rich granite dykes. Yellow scapolite associated with calc-silicate clusters in the dolomite marble is probably also related to the soda-rich intrusions. No direct evidence was found of scapolite belonging to an earlier metamorphic period. Since it is therefore regarded as a mineral more intimately associated with the granites than with the Marble Delta Group, its mode of occurrence and mineralogy are described in more detail under the heading Monomineralic Dykelets related to Granite.

(m) Sphene

Sphene is frequently found in skarn mineral assemblages and along granite contacts. Large euhedral light brown crystals (3 cm) occur in the calcite marble along the Umzinkulu River, while darker brown sphene commonly crystallized in the contact zones of amphibolite dykes and dykelets 2,5 - 100 cm wide. Opaque black sphene identified by X-ray diffraction occurs in layers containing the mineral assemblage forsterite-spinel-dolomite. In this case the sphene must

have derived its titanium from the impure calcareous sediment. The large brown sphenes in contact zones, however, are due to the reaction between the Ti-rich amphibolite dykes and their wall rocks during later metamorphic episodes. The sphene found along the contact between granite and calcite wall rock derived its titanium from the granite magma.

(n) Talc

This mineral is present as clear crystals in the cores of the diopside-serpentine clusters with occasional scapolite. Pink talc was also observed as an alteration product in veinlets, probably pseudomorphous after scapolite. It is also frequently associated with tremolite. The frequently occurring mineral assemblage tremolite-talc-calcite, which indicates disequilibrium with respect to the adjacent forsterite-diopside-calcite assemblage, is due to contact metamorphic overprinting on the earlier regional metamorphism. Water was re-introduced into the marble by the later granite intrusions resulting in the crystallization of talc.

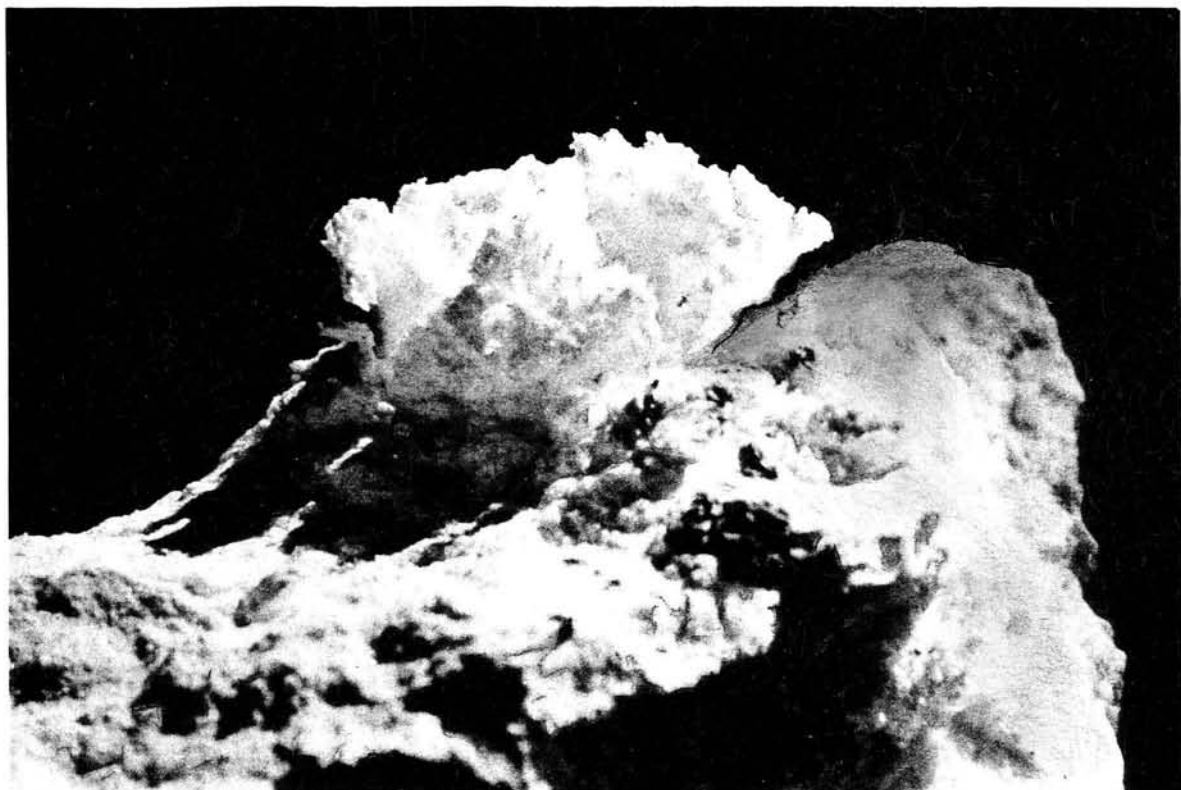
(o) Tourmaline

Tourmaline is disseminated in some of the marble beds of the Oribi Formation on Le Joncquet (Map 2, I 231). The mineral occurs as black irregularly shaped aggregates up to 4 cm in diameter, as anhedral grains in phlogopite-calcite marble, and in calcite marble (Plate X, ph 1). Tourmaline also

crystallized/



Ph 1. Photograph of irregular black tourmaline showing rounded embayments against calcite (Bed No. 1219).



Ph 2. White plume of powdery material due to partial disintegration of saponite by moisture. (Actual size).

crystallized in scapolite skarn as pale brown radiating needles (3 cm suns, colourless under the microscope).

Four tourmaline specimens were selected from the above-mentioned occurrences for X-ray diffraction study. The cell parameters and axial ratios were calculated and compared with tourmaline of known composition on Epprecht's diagram (1953). Epprecht's data have been converted from kX units to Å by Deer et al (1962) as indicated on fig. 4. The tourmalines of the Marble Delta plot close to dravite but show a serial variation across the dravite-shorl trend. It is suggested that this is due to isomorphous substitution of Na by Ca towards the end-member uvite ($\text{CaMg}_4\text{Al}_5\text{B}_3\text{Si}_6\text{O}_{27}$) in the case of specimen No. 1, which is associated with a low-iron phlogopite (see phlogopite). The low iron content is probably due to conditions which also favoured the formation of scapolite. The scapolite associated with tourmaline has a greater meionite content than the other scapolites and these minerals thus appear to have crystallized in a soda-poor part of the skarn. Donnay and Buerger (1950) found the structure of tourmaline to be complex even though the equipoints of the (Ca Na) atoms are fixed by the space-group symmetry. The increase of colour and pleochroism from tourmaline 1 to tourmaline 4 (fig. 4) is accompanied by increasing iron content of associated phlogopite and probably reflects the isomorphous substitution of Mg by Fe in tourmaline.

Except for the tourmaline in the vein of hydrothermal-scapolite emanating from the granite, the other occurrences are considered to have derived their boron from the original

sediments. The presence of boron, which has been used as a paleosalinity indicator, is in this case paralleled by high K_2O content reflected by phlogopite.

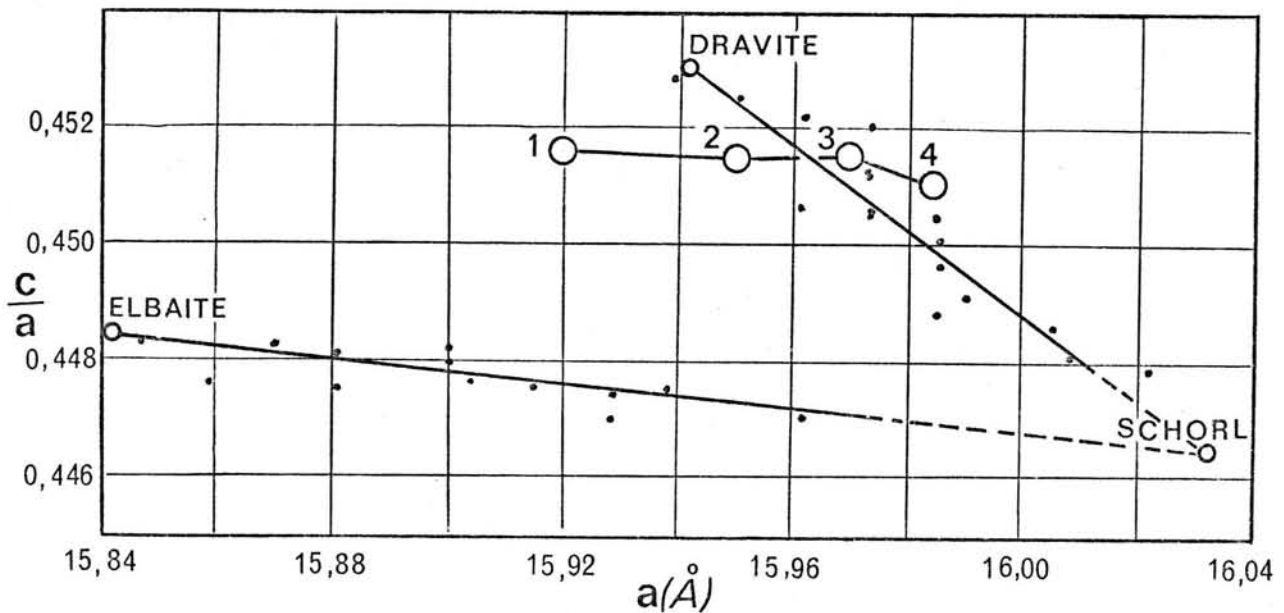


FIGURE 4. Marble Delta tourmalines :- axial ratios and cell dimensions plotted on diagram after Epprecht (1953) and Deer et al (1962).

1. Pale brown tourmaline from scapolite-skarn in calcite.
2. Dark brown tourmaline in isochemical microcline-skarn.
3. Brownish black tourmaline in calcite marble
4. Greenish black tourmaline in phlogopite marble

(p) Saponite

This mineral was found on freshly exposed surfaces of marble in the quarries. It is soft, white and greasy and is noticed only after a shower of rain has caused it to disintegrate, often forming a mushroom-shaped mound of white powder (Plate X, ph 2). Under the microscope the mineral can be observed to effervesce slowly in water. A glass mount of the specimen was heated to about 100°C and soaked in glycol for one year. The X-ray diffractogram showed that it had taken up two layers of glycol, for the $d_{(001)}$ spacing moved to 17,98⁰Å, which together with the $d_{(060)}$ spacing indicates a tri-octahedral structure; it is therefore a smectite. The d-spacings of the strongest X-ray diffraction lines are 15,38 4,53 1,52 2,58 - 2,48B 4,13 and 0,991⁰Å. The X-ray diffraction pattern closely resembles that of zebedassite (ASTM card 10 - 426) although it exhibits fewer lines. This mineral name has been discredited

but re-appears in the 1966 Kwic file and has again been removed afterwards. The name appears to be useful to distinguish it from other saponites. A slight shift of some lines in different specimens is probably due to minor variations in crystal structure.

Saponite veins, 1 - 5 mm wide, are found in serpentine in the dolomite marble (Map 3, 105 Level, GG 150). They grade into white phlogopite veins which in turn can be traced into granite veinlets. This rare mode of occurrence of saponite probably represents one of the lowest temperature mineral phases associated with granite intrusions.

(q) Other minerals

Quartz, microcline, plagioclase, hornblende and cumingtonite were also identified in the marbles. Apart from most of the minerals described above as constituents of the formations but also found in the skarn assemblages, the following minerals were only encountered in skarns: hedenbergite, zoisite, clinozoisite, allanite, chondrodite, chalcopyrite and pyrrhotite.

Among the secondary minerals black chlorite was found on Lot F 0 in association with granite. Yellow nontronite and sericite occur frequently on Le Joncquet associated with zones of late deuteric alteration. Occasional brucite probably originated by alteration of chrysotile as no brucite marble was found; this could be explained by the expulsion of H_2O during earlier regional metamorphic events leading to high P_{CO_2} which prevented the formation of periclase.

New mineral assemblages are still being uncovered with the continual advance of quarry faces, especially in the category of metamorphic-pneumatolytic skarn rocks. This area promises to be like Crestmore in California where many discoveries of new mineral species have been made over the years (Murdoch, 1961).

4. CHEMICAL COMPOSITION

Analyses published by Du Toit (1918) indicate a range in MgCO_3 content of 30,26 - 37,46 per cent in the eastern part of the Marble Delta at Lot F 0 and The Glen, and of 1,36 - 10,59 per cent on Westlands. Owing to the dearth of published chemical data, a large number of samples for analysis were collected from specific beds in the marble formations. Partial analyses were carried out on these by the Roodepoort Laboratories of Anglo Alpha Cement Ltd. Because the analyses relevant to the economically mineable units are confidential, these have been omitted and the discussion in this chapter will include only those analyses pertaining to the litho-stratigraphic units and lithological types.

Fieldwork has shown that lateral variation from east to west is more pronounced in the cluster serpentine marble than in any other stratigraphic unit. This is evident from the increase in the number of dolomite marble beds from East Slopes to Le Joncquet. The lateral variation in composition of the calcite marble of the Oribi Formation is reflected mainly by its silica content which increases progressively in an easterly direction and reaches a maximum on East Slopes, West Slopes and Kippen's Quarry.

The calc-silicate marble forming the lower part of the Le Joncquet Formation (from Bed 7175 downwards, fig. 2) may be correlated with the beds exposed on The Glen/Lot F 0 boundary on the basis of its chemical composition and mineral assemblage. Owing to the scarcity of outcrops no information is available on the lateral variation of these beds

from/

from east to west. When compared with the stratigraphically higher lying calc-silicate beds in the dolomite marble, a close resemblance is evident both in texture and mineral assemblage. The volumetric modal composition of calc-silicate marble (Table 1; representing ca. 1000-point count analyses) generally shows greater preponderance of forsterite as compared with beds higher in the succession. This may be due to the fine-grained, compact nature of this rock making it more resistant and less susceptible to the subsequent introduction of water from the granite intrusions which led to the serpentinization of forsterite higher in the succession.

Table 1: Modes of Calc-silicate Marble

<u>Bed No.</u>	<u>Calcite</u>	<u>Dolomite</u>	<u>Forsterite</u>	<u>Diopside</u>	<u>Quartz</u>	<u>Phlogopite</u>
7437	54,8	12,2	17,7	14,7	-	0,6
7455	53,2	23,2	11,1	10,6	-	1,9
7839	10,1	-	-	44,2	45,7	-
8257	53,0	11,9	14,9	14,0	-	6,2
5169	54,5	25,1	17,1	3,0	-	0,3

The mode of Bed No. 5169 compares very well with that of the thick succession of calc-silicate marble indicating that similar sedimentary conditions periodically recurred during deposition.

The dolomite marble which is noted for its interstitial calcite was specifically sampled across the succession over a 30-metre zone upwards from Bed No. 7175. Comparison of

this/

this analysis (Table 2, No. 2), with that of various other localities (Nos. 1 and 3 to 7) shows that the marble is characterised by a rather constant composition.

Table 2: Chemical analyses and norms* of Dolomite Marble

<u>Analysis</u> <u>No.</u>	<u>Locality</u>	<u>SiO₂</u>	<u>Al₂O₃</u>	<u>Fe₂O₃</u>	<u>MgO</u>	<u>CaO</u>	<u>Na₂O</u>	<u>K₂O</u>	<u>Loss</u> <u>Ign.</u>	<u>Total</u>
1.	Site II 160	1,3	0,3	0,2	18,8	34,6	-	-	44,7	99,8
2.	Site W 155	1,0	0,4	0,1	18,1	34,7	-	-	45,6	99,9
3.	Lot F 0	0,7	0,13	0,17	18,0	34,6	0,02	0,08	45,2	98,9
4.	Lot F 0	1,9	0,46	0,04	19,2	34,2	0,02	0,03	44,2	100,05
5.	Lot F 0	7,2	0,86	0,04	18,0	36,6	0,05	0,06	37,1	99,91
6.	Bed No. 5691	2,0	0,38	0,02	18,5	34,7	0,14	0,02	44,4	100,16
7.	Bed No. 4953	1,6	0,28	0,02	18,0	35,8	0,16	0,10	44,0	99,96

	<u>Dolomite</u>	<u>Calcite</u>	<u>Diopside</u>
Site II 160	83,9	15,3	2,4
Site W 155	81,3	17,2	1,7
Lot F 0	81,9	17,3	0,4
Lot F 0	84,8	13,6	3,5
Lot F 0	71,2	17,3	13,0
Bed No. 5691	81,7	16,1	3,5
Bed No. 4953	78,9	19,2	3,9

*All norms in Tables 2, 4, 5 are expressed as weight percentages.

The calculated norm was confirmed by macrometric modal analysis on alizarin-stained dolomite specimens.

The remarkable consistency of MgO content, which persists (together with the presence of interstitial calcite) in different stratigraphic positions, and in beds of different texture which have been subjected to different intensities of metamorphism, indicates that there was a chemical control over the amount of calcite precipitated during the deposition of the sediments. A constant percentage of calcite is also characteristic of the dolomite beds intercalated with the calcite marble and in stratigraphically higher positions.

Graphite becomes prominent as the silica content of the dolomite increases together with an increase in the number of quartzite lenses upwards in the succession. In the upper part of the Le Jonquet Formation on top of the main dolomite member, the silica content varies from 0,3 per cent in the intercalated massive dolomite to 23,3 per cent in banded calc-silicate marble. The lateral variation towards the east is marked by the disappearance of the interbedded dolomite and an increase in silica content present as calc-silicates and quartz (Table 3, anal. 30 - 40, percussion drill samples collected over total stratigraphic thickness of 27 metres between 202 m and 175 m above msl at LL 170).

From the changeover of dolomite marble to the calcitic rocks of the Oribi Formation, there is a significant decrease of the silica content accompanying the disappearance of prominent quartzite bands. The dispersed silica of the calcite-marble remains more or less constant in any specific area

Table 3: Chemical analyses of layers in upper Le Joncquet Formation

<u>Anal.</u> <u>No.</u>	<u>Locality</u>	<u>SiO₂</u>	<u>Al₂O₃</u>	<u>Fe₂O₃</u>	<u>MgO</u>	<u>CaO</u>	<u>Na₂O</u>	<u>K₂O</u>	<u>Loss</u> <u>Ign.</u>	<u>Total</u>
8	Bed 4971	20,7	0,2	0,3	16,3	34,5	-	-	27,5	99,5
9	Bed 4999	13,4	0,96	0,24	16,2	34,4	-	-	33,9	99,1
10	Bed 5054	1,0	0,42	0,08	18,1	34,8	-	-	45,3	99,7
11	Bed 5085	4,0	0,62	0,08	17,9	35,5	-	-	41,7	99,8
12	Bed 5099	16,6	0,34	0,16	16,3	33,8	-	-	32,3	99,5
13	Bed 5118	3,3	0,54	0,16	19,1	34,8	-	-	42,4	100,3
14	Bed 5169	21,3	0,76	0,24	19,1	32,8	-	-	25,0	99,2
15	Bed 5207	0,3	0,36	0,04	18,3	35,1	-	-	45,8	99,9
16	Bed 5246	3,7	0,62	0,08	18,7	35,0	-	-	41,6	99,7
17	Bed 5258	11,7	0,3	0,4	19,1	35,4	-	-	33,2	100,1
18	Bed 5414	7,4	0,58	0,12	18,6	35,6	0,04	0,06	37,6	100,0
19	Bed 5663	2,7	0,86	0,04	17,9	35,2	-	-	43,1	99,8
20	Bed 5724	4,9	1,16	0,24	18,2	34,9	0,07	0,19	40,2	99,86
21	Bed 5791	2,4	0,62	0,08	18,0	35,5	-	-	43,3	99,9
22	Bed 6023	2,1	0,52	0,08	16,6	37,2	-	-	43,6	100,1
23	Bed 6041	6,3	0,62	0,08	15,0	37,8	0,08	0,05	40,1	100,03
24	Bed 6276	4,3	0,62	0,08	18,0	35,8	0,14	0,04	41,0	99,98
25	Bed 6386	0,6	0,38	0,02	18,1	35,3	-	-	45,4	99,80
26	Bed 6514	0,9	0,58	0,02	18,0	35,4	-	-	45,0	99,9
27	Bed 9062	17,2	1,3	0,2	18,8	34,8	-	-	28,0	100,3
28	Bed 9306	84,8	4,0	1,3	3,0	5,2	-	-	1,5	99,8
29	Bed 9327	7,4	1,2	0,6	17,2	35,0	-	-	38,1	99,5
30	Site LL 170	15,0	0,72	0,08	14,4	37,4	0,03	0,04	32,1	99,77
31	"	16,1	0,56	0,04	15,9	35,6	0,04	0,06	31,7	100,0
32	"	9,8	0,36	0,04	15,1	37,8	0,03	0,04	36,6	99,77
33	"	17,7	0,56	0,04	15,0	34,8	0,05	0,06	31,9	100,11
34	"	6,3	0,52	0,08	17,0	35,8	0,02	0,03	40,2	99,95
35	"	1,7	0,56	0,04	17,3	36,0	0,02	0,03	44,2	99,85
36	"	1,5	0,42	0,08	17,8	35,6	0,03	0,07	44,4	99,9
37	"	2,8	0,66	0,04	17,6	35,1	0,03	0,04	43,6	99,8
38	"	13,9	0,62	0,08	17,4	34,3	0,04	0,05	33,6	99,99
39	"	23,3	0,58	0,02	15,1	34,6	0,04	0,04	26,0	99,68
40	"	6,3	0,52	0,08	17,3	35,3	0,03	0,06	40,3	99,89

except for the interbedded siliceous beds such as the wollastonite-diopside marble and occasional thin quartzite layers. On the whole the silica content varies laterally and vertically by similar amounts as indicated by the analyses in Table 4. From the 130 Level (Site H 220, Bed Nos. 415 - 500) southwards along the strike of the calcite marble silica increases to an average of 2,17 per cent at the Rayon Quarry (Site W 260) and to 3,49 per cent about one kilometre further south toward the Umzimkulwana River.

Table 4: Chemical analyses and norms of Calcite Marble

<u>Anal.</u> <u>No.</u>	<u>Locality</u>	<u>SiO₂</u>	<u>Al₂O₃</u>	<u>Fe₂O₃</u>	<u>MgO</u>	<u>CaO</u>	<u>Na₂O</u>	<u>K₂O</u>	<u>Loss</u> <u>Ign.</u>	<u>Total</u>
41	Bed 415	0,5	0,34	0,16	2,3	52,8	0,00	0,00	43,4	99,50
42	Bed 420	0,8	0,79	0,41	2,0	52,4	0,00	0,00	43,2	99,60
43	Bed 500	0,3	0,64	0,16	2,5	52,6	0,00	0,00	43,3	99,50
44	Bed 543	6,0	0,27	0,02	1,1	53,5	0,01	0,01	38,9	99,81
45	Bed 714	0,4	0,14	0,15	3,0	52,6	0,01	0,01	43,4	99,71
46	Bed 874	0,5	0,06	0,03	0,6	55,5	0,01	0,02	43,0	99,72
47	Bed 1231	5,8	0,12	0,08	0,2	55,6	0,00	0,00	37,8	99,60
48	Bed 1536	0,3	0,13	0,06	0,6	55,5	0,01	0,01	43,1	99,17
49	Rayon Quarry ¹⁾	2,17	0,44	0,06	1,34	53,56	-	-	42,32	99,89
50	Umzimkul- wana R. ²⁾	3,49	0,84	-	0,57	52,74	(0,49) ³⁾		41,85	99,98

1) Average of 10 analyses

2) Average of 5 analyses

3) SO₃ percentage

Table 4: (Continued)

<u>Analysis No.</u>	<u>Calcite</u>	<u>Dolomite</u>	<u>Diopside</u>	<u>Wollastonite</u>
41	89,2	9,9	0,9	-
42	90,4	8,2	1,4	-
43	88,3	11,2	0,4	-
44	83,3	5,0	-	11,7
45	86,4	12,8	0,8	-
46	97,1	2,0	0,9	-
47	87,9	0,9	-	11,2
48	97,3	2,2	0,5	-

The calcite marble on East Slopes includes a number of interbedded bands with a SiO_2 content of 49,7 per cent and higher (see Plate V, pm 1). Across the river on Westlands, The Vineyard and Lot F A 1, the layers are less siliceous but have correspondingly higher magnesia. The silica on East Slopes is present almost entirely as quartz with little wollastonite (Table 5).

Table 5: Chemical analyses and norms of Quartz-Calcite Marble

<u>Anal. No.</u>	<u>Locality</u>	<u>SiO_2</u>	<u>Al_2O_3</u>	<u>Fe_2O_3</u>	<u>MgO</u>	<u>CaO</u>	<u>Na_2O</u>	<u>K_2O</u>	<u>Loss Ign.</u>	<u>Total</u>
51	East Slopes	49,7	0,23	0,12	0,7	28,2	0,14	0,06	20,6	99,75
52	East Slopes	14,3	0,13	0,04	0,8	48,2	0,08	0,06	36,2	99,81
53	East Slopes	37,3	0,18	0,08	0,6	35,0	0,10	0,06	26,6	99,92
		<u>% Quartz</u>		<u>% Calcite</u>		<u>% Diopside</u>		<u>% Wollastonite</u>		
51	East Slopes	47,0		47,2		3,7		2,1		
52	East Slopes	10,9		82,6		4,3		2,2		
53	East Slopes	35,7		60,9		3,2		0,2		

IV PRE-CAPE INTRUSIONS

1. AMPHIBOLITE DYKES AND SILLS

A distinction was made between the amphibolite which occurs within the marble area in the form of dykes and sheets, and the amphibolite of the Cherrywillingham Formation. The difference is based on the mode of occurrence and on composition. The age relationship between the two types of amphibolite is not known except that both have been subjected to the same intensity of metamorphism before the intrusion of the granites.

The amphibolite which may be interpreted as meta-dolerite has been emplaced in lit-par-lit fashion in the marble, yet in a few rare instances the intrusions cut across the bedding trace (Quarry on 150 Level, N 225) and form boudinaged structures that were accentuated during later flowage of the marble. It is considered that cross-cutting relationships are rare because they were subsequently modified by flowage of the marble during metamorphism. In the case of dolomite marble which was more competent than calcite marble during deformation, the amphibolite is often folded with the host rock (W 105 Level, site HH 170). In the calcite marble on the other hand, the ductility contrast between the two rock types is so great that the amphibolite is frequently broken into blocks while the marble is plastically deformed.

The dykes vary from a few cm to about one metre in thickness. The thin sheets, a few cm wide, have a decidedly finer-grained texture than the larger dykes and this seems

to indicate that the original crystallinity played a part in determining the eventual grain size acquired during recrystallization caused by metamorphism. The constituent minerals are hornblende with subordinate plagioclase. Reaction zones with the calcite wall-rock frequently form a rim around the broken-up blocks of amphibolite. The width of the zone varies from place to place, increasing at the free end or along pre-existing structural features in the amphibolite. The type of reaction and resulting minerals depend on the distance from the intrusive as well as the components of dyke material and host rock. One such reaction product is described under skarn and the process of formation is termed "induced contact metamorphism".

Comparison of the three analyses of amphibolite dykes and sills in Table 6 shows a trend of decreasing Al_2O_3 , MgO and Na_2O with a concomitant increase in CaO and K_2O . The Cherrywillingham amphibolite shows a higher MgO and lower CaO content than the others but their overall composition is rather similar. The chemistry of the amphibolites is further discussed under Petrogenesis.

Table 6: Chemical analyses and niggli values of Amphibolites

	1	2	3	4
SiO ₂	44,10	44,4	44,00	45,0
TiO ₂	-	-	2,0	-
Al ₂ O ₃	16,36	14,96	13,16	12,83
Fe ₂ O ₃	11,20	10,9	1,93	14,15
FeO	-	-	7,18	-
MnO	0,03	0,04	0,14	0,07
MgO	12,30	11,8	9,26	14,60
CaO	11,60	12,2	16,92	9,6
Na ₂ O	2,78	2,45	1,17	1,36
K ₂ O	0,40	0,75	1,12	0,36
H ₂ O ⁺	1,20	2,0	1,29	1,85
H ₂ O ⁻	-	-	0,09	-
P ₂ O ₅	0,10	0,10	0,42	0,22
CO ₂	-	-	1,55	-
Total	100,04	99,60	100,23	100,04

si	85	88	84	87
al	18,5	17,4	14,7	14,6
fm	51,9	51,0	43,7	62,6
c	23,9	25,9	34,5	19,8
alk	5,7	5,7	7,1	3,0

1. Average of two amphibolite analyses, 165 Level
(AA Lab. Roodepoort)
2. Amphibolite from dyke on 130 Level, H 220
(AA Lab. Roodepoort)
3. Amphibolite, Lot 21 Quarry, Site N/O 254
(Simpson and Tregidga, 1956)
4. Average of four analyses of amphibolite
(Cherrywillingham Formation Lot F N, Site 5R 2223)

2. N'DONGENI BASIC ROCKS

A suite of gabbroic, dioritic, and basic nepheline-bearing rocks with subordinate syenite is located in the northwestern part of the Marble Delta. Since they do not seem to form a single unit and because definite evidence of consanguinity could not be found, the term "igneous complex" is considered inappropriate. The exposures are poor and occur close to the northern boundary of N'Dongeni, along the western boundary of Watershed and on Buffalo Bill. The outcrops are not readily distinguishable in the field from altered amphibolites, charnockitic rocks and granulites. On Buffalo Bill and Watershed the rocks form lenticular outcrops reminiscent of dykes but the large number of rounded inclusions contained in the adjacent St. Faith's granite and Buffalo Bill granite, suggest that these basic rocks may be in the form of stoped rafts. Flattened inclusions are found in the fine-grained granites on the northern boundary of N'Dongeni (Map 1, block 7D) as well as in the granitic rocks close to the Renkin fault.

The age relationship of these basic rocks with respect to the metasediments of the Marble Delta Group is not clear, since no direct contacts are available. However, the fact that the basic rocks occur close to the upper part of the Oribi Formation which underwent extensive mobilization on the northwestern side (clinopyroxene-calcite marble), indicates that they probably did not form part of the basement on which the sediments were deposited. This inferred post-Marble Delta Group age is further supported by the presence

of calcite and garnet in a nepheline-bearing gabbro closer to the marble contact.

The gabbroic suite of rocks crop out extensively on Buffalo Bill where, from west to east, they vary from gabbro through leuco-gabbro, and monzo-gabbro to meladiorite.

(a) Hornblende-pyroxene gabbro

The main outcrop of this rock type occurs on and near site 6B 1312. The gabbro has an even-grained texture of 1 - 2 mm. The dominant plagioclase is labradorite (An_{55} ; $2V_{\gamma}$ 80°) characterized by narrow and tapered twin lamellae. The fact that the twin lamellae are flexured and bent indicates that the rock was subjected to deformation either during regional metamorphism or after recrystallization when the nearby granite was emplaced.

About 250 metres to the south-west (Site 6B 3133) the gabbro is fresh, equigranular (0,5 - 1,5 mm) and the clear labradorite twins are broad, showing no sign of deformation. The rock contains more orthopyroxene and almost the same amount of hornblende, but less clinopyroxene. The hornblende replaces orthopyroxene leaving skeletal remains of the host which also show alteration along the fine lamellar twinning. The volumetric modes of the gabbro from the two sites are:

	<u>6B 1312</u>	<u>6B 3133</u>
labradorite	75,4%	68,9%
hornblende	16,1%	15,5%
orthopyroxene (with sub- ordinate clinopyroxene)	5,0%	10,0%
biotite	3,5%	5,6%

According/

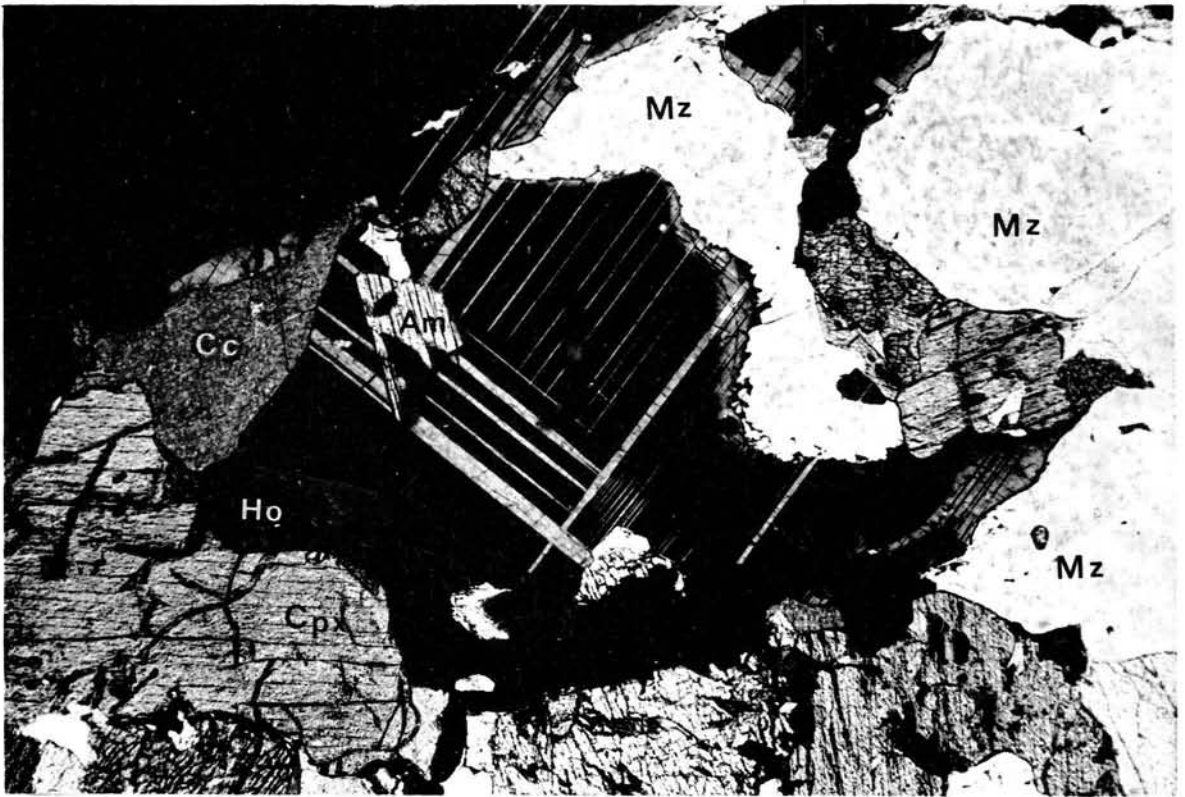
According to Streckeisen's (1967) classification of modal compositions for plutonic rocks, they fall within the leucogabbro field.

West of the above localities coarser patches in gabbro (0,5 - 1 cm) consist of labradorite (An_{61-66} ; $2V_{\gamma}$ 78° - 82°) together with bytownite (An_{72}) both of which have clear broad twin lamellae without any dust-like inclusions or alteration. The gabbro consists mainly of plagioclase and orthopyroxene with subordinate hornblende and biotite.

Coarser irregular zones in the gabbro are present to the north-west towards the St. Faith's granite contact, due to scapolitization and epidotization. The scapolite is present as distinct grains in the matrix of the rock. X-ray diffraction analysis shows a peak separation of $0,45(2\theta_{325} - 2\theta_{751} \text{ CoK}_{\alpha_1})$ which corresponds to that of G, fig. 6, indicating a calcic mizsonite. The outline of the plagioclase (An_{45} ; $2V_{\gamma}$ 74°) is smooth and undulating, indicating that resorption took place before it was rimmed by labradorite with an anorthite content of 60 - 65 per cent. This calcic rim is present only where it is in contact with mizsonite, but no rim is formed against calcite, green amphibole (γ/c 9°) or orthopyroxene (Plate XI, pm 1).

(b) Mela-diorite

The leuco-gabbro body thins out towards N'Dongeni and passes into hypersthene-hornblende gabbro. The prominent outcrops at site 7C 1112 have plagioclase with a lower anorthite content (An_{40-42} ; $2V_{\gamma}$ 74° - 81°) and are classified



Pm 1. Photomicrograph of gabbro showing single plagioclase grain (An_{45}) with continuously zoned rim (An_{60}) against mizzonite (Mz) but not against calcite (Cc), clinopyroxene (Cpx), hornblende (Ho) or green amphibole (Am). (Crossed nicols, X80).



Pm 2. Photomicrograph of diorite with ilmenite rimmed by sphene in a matrix of plagioclase and biotite. The plagioclase shows very little deformation compared with plagioclase from other basic rocks. (Crossed nicols, X70).

as mela-diorite. The plagioclase is clear and shows no deformation or alteration except for a few cracked grains denoting a volume change during final consolidation of the magma. The orthopyroxene ($2V_{\alpha} 55^{\circ}$) often includes euhedral crystals of hornblende in contrast with the usual scalloped contacts between the two minerals. The volumetric mode of a sample taken at site 7C 1112 is:

plagioclase	51,7%
orthopyroxene	22,4%
hornblende	10,1%
magnetite, ilmenite	3,6%
pyrite	0,2%

(c) Diorite

The dyke-like bodies of diorite, striking in a southeasterly direction towards the Buffalo Bill/Watershed boundary, exhibit a foliation which is not present in the basic bodies to the west. In the field the westernmost occurrence (Site 8B 1341) has a characteristic appearance with its white feldspar and hornblende and in thin section shows ilmenite with coronas of sphene (Plate XI, pm 2). Further east (Site 8B 3214) the dyke-like bodies are more banded. Large insets of orthopyroxene are conspicuous together with green augitic clinopyroxene as well as a greater percentage of biotite as seen in the volumetric modes of Table 7.

Table 7: Volumetric modes of dioritic dyke-like bodies

<u>Locality</u>	<u>8B 1341</u>	<u>8B 3214</u>	<u>8C 2413</u>	<u>9C 1332</u>	<u>9C 1332</u>
Plagioclase	82,1	64,1	51,2	60,9	68,6
Hornblende	11,0	17,1	21,7	0,4	-
Clinopyroxene	3,4	7,6	24,9	22,3	0,5
Orthopyroxene	-	2,4	-	-	-
Biotite	2,3	8,6	0,0	16,4	4,1
Ore minerals	0,9	0,0	2,1	-	0,0
Apatite	0,3	0,2	0,1	-	0,0
Quartz	0,0	0,0	0,0	0,0	26,8

About 100 metres towards the south there is another dyke-like body characterized by the fine-grained texture of the groundmass (0,4 mm) and phenocrysts of zoned calcic plagioclase (2 - 3 mm). The cores of these phenocrysts are saussuritized. Occasional larger crystals (3 - 4 mm) of clinopyroxene occur amongst the finer-grained clinopyroxene (0,3 mm). Graphite flakes are present along grain boundaries in the groundmass.

North and south of the latter occurrence (sites 9C 1332 and 8C 4233) the rock types are decidedly different, showing incipient development of schistosity. Common hornblende or an exceptionally dark green amphibole together with a bluish green amphibole occur with the green clinopyroxene. The plagioclase shows faint lamellar twinning, typical of deformed or gneissic rocks. At site 9C 1332, layers are present (1 cm thick) which may contain up to 26,8% quartz as shown in the modal analysis (Table 7).

(d) Syenite

Syenite occurs on Buffalo Bill (site 7D 4112) in a 30 metre wide zone in granitic rocks. The plagioclase (18,6%) shows flexured, tapered and faint lamellar twinning indicative of deformation. The potash feldspar which is the main constituent (66,2%) does not show the gridiron twinning of microcline and forms rounded grains with thin perthitic exsolution lamellae. Amphibole (14,2%) shows strong absorption from dark green (γ) to yellowish green (β) with $2V_{\alpha}$ 52° ; γ/c 15° . A pale greenish amphibole is also present. Towards the north-west the syenite seems to grade into monzonite (site 8D 1144) having similar mineralogy but more plagioclase.

(e) Theralite, Ijolite and Melteigite

Isolated bodies of gabbro are situated closer to the marble contact than any of the aforementioned gabbroic rocks and may belong to the syenite-monzonite sequence further west. The texture is variable in the field from coarse-grained to fine-grained types which, due to poor exposures, may be difficult to distinguish from hybrid rocks resulting from the assimilation of amphibolite by granite. The coarser rocks are, however, notable for their nepheline and aegirine-augite content, grading from theralite to ijolite and melteigite with local coarse pyroxenitic types. Euhedral nepheline (3 cm) and aegirine-augite up to 5 cm in diameter are found in coarse-grained zones but generally the fabric is

interlocking/

interlocking. Sphene (up to 2 cm) varies in grain size together with the main constituents and ranges in colour from brown to pale yellow. Fine-grained (4 mm) ijolite which occurs in dyke-like form, is apparently a representative sample of this rock type with its generally irregular texture; its volumetric mode is as follows:

nepheline	46,1%
aegirine-augite	46,6%
amphibole	1,5%
magnetite and pyrite ..	2,0%
garnet	2,6%
apatite	1,2%

In addition to these constituents a green amphibole ($2V_{\gamma} 62^{\circ}; \gamma/c = 13^{\circ}$) sphene, plagioclase and calcite is present as major accessories in the ijolite. Calcite relics are armoured by a complete rim of garnet (Plate XII, pm 1,2). Garnet generally forms a rim along the grain boundaries of nepheline and aegirine-augite. A clear rim of late oligoclase (An_{15}) instead of garnet is formed against slightly seriticized nepheline especially where the nepheline is in contact with pre-existing slightly altered plagioclase (An_{23}). The rim of oligoclase is often continued as garnet or green amphibole. The scalloped outlines of aegirine-augite and nepheline showing late magmatic resorption effects as well as the presence of euhedral crystals, no doubt indicate a magmatic as opposed to a metasomatic (nephelinization) origin of these rocks. The armoured relics and reaction rims show that calcite was assimilated by the gabbroic magma

and/

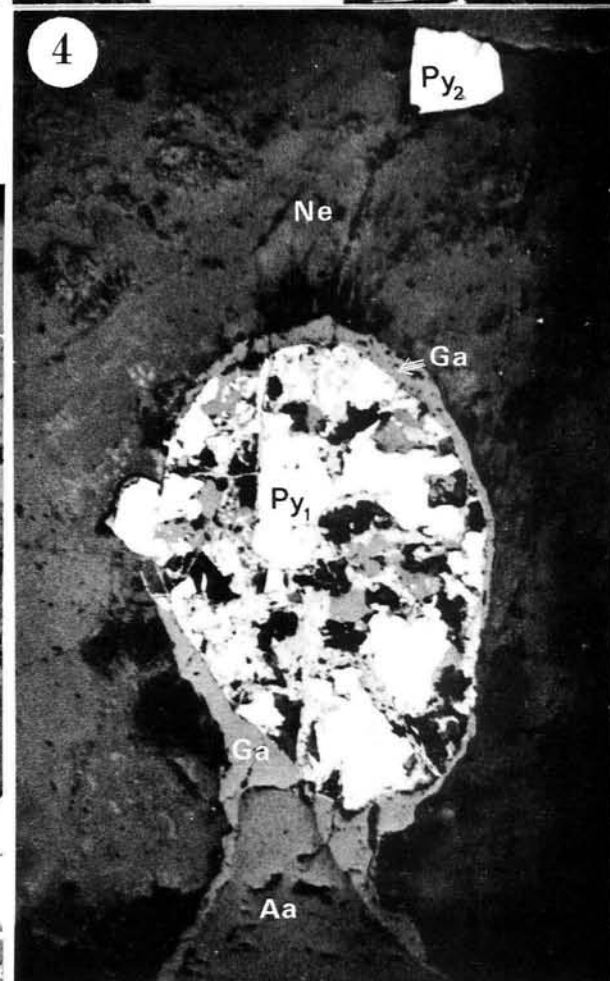
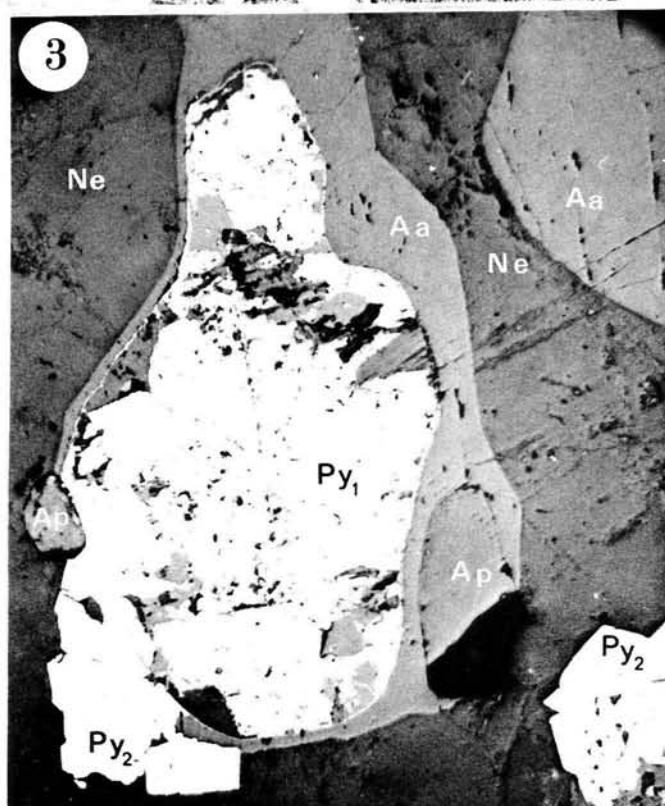
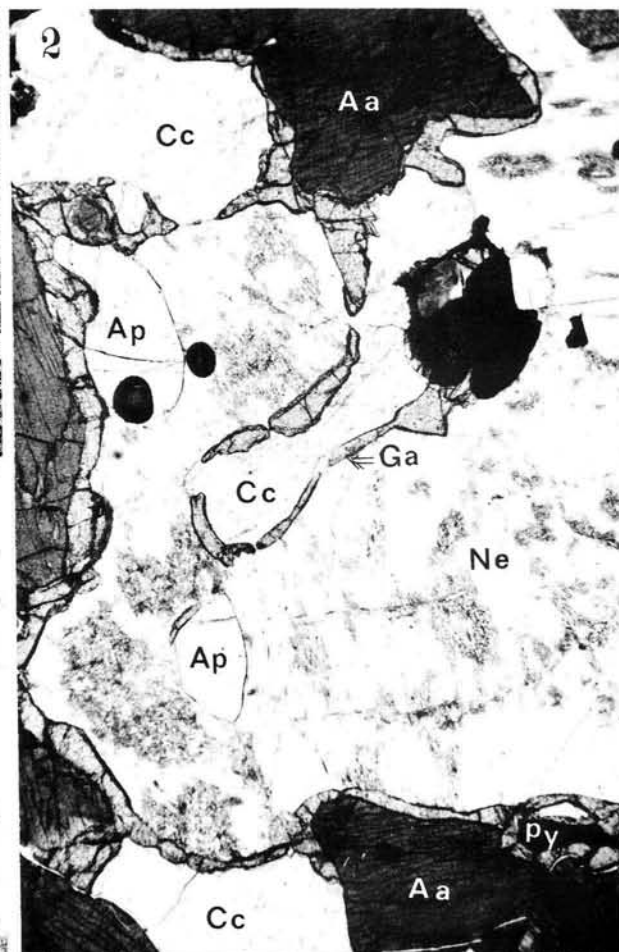
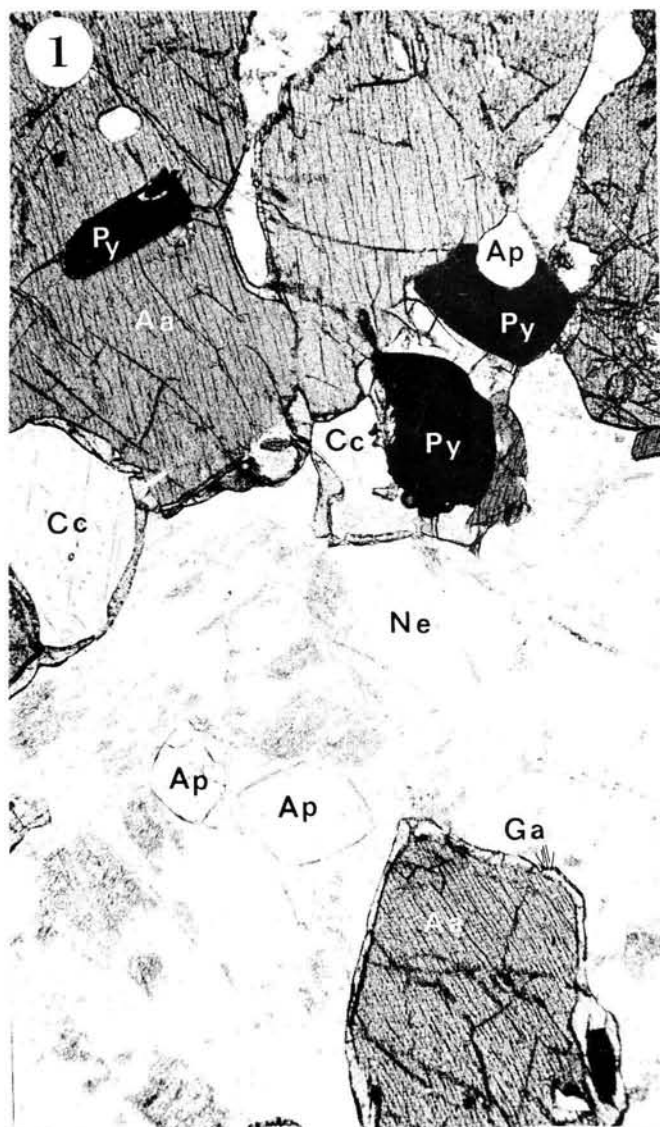


PLATE XII

Photomicrographs 1, 2, 3 and 4 of medium-grained ijolite.

- Pm 1. Aegirine-augite (Aa) and nepheline (Ne) rimmed by pink garnet (Ga). The garnet surrounds the accessory minerals calcite (Cc), apatite (Ap) and pyrite (Py). Rounded apatite is present in pyrite and aegirine-augite (ordinary light, X60).
- Pm 2. Rounded apatite and calcite included in nepheline which shows patches of alteration. Note absence of garnet rim on calcite contact against aegirine-augite in lower left hand corner (ordinary light, X60).
- Pm 3. Rounded pyrite grain with replacement patches of a grey ore mineral and digenite. The grain is surrounded by an aegirine-augite rim which includes apatite. A second stage euhedral pyrite (P₂) is present outside the original boundary (reflected light, X115).
- Pm 4. Composite pyrite grain similar to Pm 3 but rimmed by garnet in a groundmass of nepheline. A second stage pyrite is seen in the upper right hand corner (reflected light, X150).

and could have contributed to its desilication in accordance with the Daly-Shand hypothesis. However, if this process operated on any appreciable scale, one would expect to find garnet or other lime silicates in amounts comparable to that of nepheline.

The ijolite contains disseminated sulphides which are present intergranularly. Pyrite grains are usually rounded and are often rimmed with garnet which encloses the apatite grains as well. Ore-microscopy shows that pyrite is replaced by magnetite and digenite. Covellite formed occasionally around chalcopyrite, which shows exsolution structures with a grey mineral. In addition to these an unidentified grey to purplish sulphide with strong pleochroism and anisotropy is present. The mode of occurrence of these sulphide minerals in the form of rounded grains (Plate XII, pm 3, 4) in a calcite-bearing nepheline-gabbro is illuminating. The presence of calcite and the proximity of marble indicates that high X_{CO_2} developed which probably played a significant rôle in the formation of minerals in the ijolite. Fluctuating f_{O_2} could explain the difference between the rounded and resorbed first stage pyrite associated with magnetite and the euhedral second stage pyrite. Such fluctuations must have influenced the f_{S_2} of the magma and probably caused sulfides to separate at various times upon cooling. This took place before final consolidation as indicated by the resorption boundaries and rims already described.

3. GRANITIC ROCKS

The granites and gneissose rocks of the Marble Delta have not been differentiated on previous geological maps (Du Toit, 1918, 1946; Simpson and Tregidga, 1956; Geological Survey 1:1 000 000 map of South Africa, 1970). Draper (1895) thought that the calcareous beds were originally deposited on granite, although he also described an intrusive granite dyke. Anderson (1907) had no doubts about the intrusive relationship of granite towards the schistose and marble beds. Boudinaged structures simulating boulders of granite in marble led Hatch and Rastall (1910) to conclude erroneously that granite was enclosed by limestone during deposition and subsequently modified by metasomatism along contacts, although they recognised intrusive granite as well. Du Toit (1919, 1946) and Simpson and Tregidga (1956) emphasized the intrusive nature of the granites.

Simpson and Tregidga (1956) made a distinction between Eastern Gneisses, Western Gneisses and Oribi Gorge Granites and included the charnockitic rocks with the granites. The granites were considered to be in situ products of secondary magmas derived from pre-existing sediments and the charnockitic suite was ascribed to granulite facies metamorphism, perhaps aided by metasomatic activity, which led to transformation of granodioritic and olivine monzonitic igneous rocks. McIver (1963) mapped the granites in detail along the coast south of the Marble Delta, and demonstrated the occurrence of a wide variety of charnockitic rock types and granites. It is obvious that these coastline granites must

be represented to a large extent inland as well. However, because a large unmapped region intervenes between the two areas, no alternative existed but to apply new local names to the granites of the Marble Delta. Even here all the age relationships have not yet been established. The following granite bodies have been distinguished and are arranged approximately from the oldest to the youngest:-

1. The Wolds garnetiferous granite (gneiss)
2. St. Helen's Rock granite
3. St. Faith's porphyritic granite
4. Westlands granite
5. Umzimkulwana fine-grained granite
6. Oribi Gorge porphyritic granite and charnockites
7. Buffalo Bill porphyritic granite
8. Granite dykes in marble

The age relationships between The Wolds, St. Faith's and Westlands granites are obscure due to lack of critical exposures. The Westlands granite and Umzimkulwana fine-grained granite may be of the same age. The Buffalo Bill granite and the Oribi Gorge porphyritic granites may be similarly related. The profusion of granitic dykes which intruded the Marble Delta cannot always be correlated with the parent intrusion and are, therefore, discussed separately.

(a) The Wolds Granite

Field Occurrence

The Wolds granite is a gneissose garnet-bearing granite, typical of the high-lying area east of the Marble Delta, and forms the prominent hill-sides on the farms West Slopes and The Wolds. Massive outcrops (buttocks) form part of the lower-lying landsurface which probably corresponds with the second phase late-Cainozoic planation of King (1967). The granite crops out in the north near Cherrywillingham Park and can be followed southwards where it parallels the amphibolite with an intervening darker garnetiferous (hybrid) granitic zone which shows no topographic expression owing to its much more weathered nature. On Hebron a separate sheet of The Wolds granite lies below this hybrid granite with rafts of amphibolite. Fresh exposures of The Wolds granite are slightly greenish in colour, reminiscent of the western porphyritic granites, the charnockitic varieties and the younger granite dykes in the marble. In the northern part of the Marble Delta a few bodies of granite with clusters of garnet are similar in appearance to The Wolds granite. In the southern part of the Marble Delta only a few outcrops occurring on Lot F N, Lynwood and The Tops can be equated with The Wolds granite. One occurrence is a dyke-like body intrusive into a garnet-granulite. The other outcrops are further west, south of the secondary dolomite.

On the southernmost bend of the Umzimkulwana River, The Wolds granite appears to grade into the garnet granulites

but on closer inspection a crushed zone was found to traverse the critical area.

Age Relationships

The Wolds granite incorporates amphibolite as inclusions and is traversed by a wide variety of granite dykes up to several metres in width. The Wolds granite in turn is broken up and included as xenoliths in younger intrusions in the southwestern part of the farm Lynwood. It antedates the Buffalo Bill and Oribi Gorge porphyritic granites and charnockitic rocks but its relationship to the St. Helen's Rock and Westlands granites is not clear. Like The Wolds granite these fine-grained types occur as inclusions in the porphyritic granite. On indirect evidence The Wolds granite is considered to antedate the fine-grained granites because its gneissosity and structure are concordant with the marble, whereas the Westlands granite appears massive.

Structure

This granite has a conspicuous concordant attitude and almost appears sheet-like in form, with a dip of 30° to the south. Foliation is developed to such an extent that it could be called granite gneiss in certain places. The lineation plunges to the S.E. and is parallel to linear structures in the marble on the opposite bank of the river on Lot F O. Cliffs are roughly parallel to the strike of this sheet-like body, but the slight divergence of the rocky cliff-line on Westlands is due to a porphyritic granite dyke not indicated on the geological map. Thus The Wolds granite

appears/

appears at first sight to be a granitized sedimentary layer on top of the Cherrywillingham Formation. However, the granite encloses amphibolite which retained its original linear fabric, orientated at an angle to the granite foliation as well as adjacent inclusions, indicating that this granite is not only an intrusive but also later than the regional high-grade metamorphic period. Faint gneissose structures in the granite are intersected by conspicuous pale streaks of felspar which also constitute the main foliation. Thin trails or wisps of micaceous minerals are sometimes obliquely arranged and also crenulated with respect to the main foliation. The lineation is superimposed on the crenulated structures which have become boudinaged in the same direction with a plunge of 20° to the east. The lenticular pale streaks in this granite, with eyes of garnet, are ascribed to movement. It seems likely that deformation of this granite took place more or less during its emplacement and that the stress pattern changed before final consolidation.

Texture and Mineralogy

The Wolds granite with its typical gneissose texture has a matrix ranging in grain size from about 1 mm to 4 mm. Clusters of garnet stand out within whitish streaks which thin out along the gneissosity of the granite, often joining one garnet cluster to another. There is a notable reduction in grain size of garnet towards the south. At the old ropeway cutting (confluence of the two rivers) the clusters

are/

are about 1 cm in size. The grain size variation of garnet can be correlated with units in the granite as discussed under structure. In the most prominent zone where The Wolds granite forms large outcrops, the garnet clusters vary from 1,6 to 3,0 (average 2,06) cm across. Towards the east, in the next "overlying sheet" the garnet averages 6 mm and becomes variable in size. It is more widely disseminated within the granite and rarely accompanied by the pale streaks.

(b) St. Helen's Rock Granite

A vertical cliff face on the Umzimkulu River a few hundred metres south of its confluence with the Umzimkulwana River consists of a fine-grained granite which Draper (1895) mistook for Table Mountain Sandstone. This granite is different from The Wolds granite on the opposite bank of the river. Until it is proved that this fine-grained granite is a textural variety of The Wolds or Westlands granites, it is provisionally called the St. Helen's Rock granite. This granite is continued westwards along the southern boundary of mapped area. It shows an increase in garnet content which distinguishes it from the texturally similar Umzimkulwana granite. It is very similar to the Margate granite described by McIver (1963).

(c) St. Faith's Granite

In the northern part of the Marble Delta (Map 1, 7A to 11D) a coarsely porphyritic granite forms a prominent range of hills. This granite builds the escarpment in the

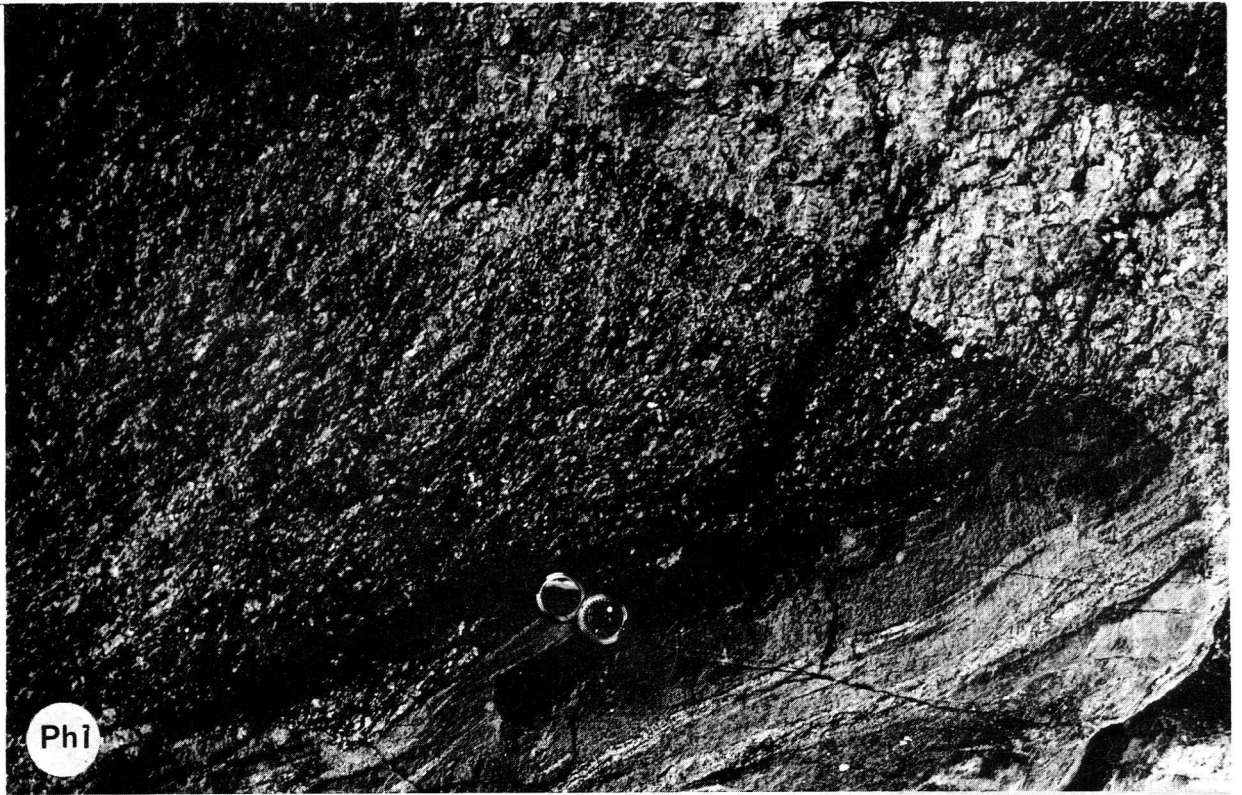


PLATE XIII.

Ph 1. Granite dyke cutting across St.Faith's granite with porphyroblastic texture. (Map 1, site 7A).

Ph 2. Aplitic segregation transecting the foliation but also incorporating K-felspar insets of St.Faith's granite. Transition between aplite and host rock visible at lower right-hand side of photograph (site 7A).

Ph 3. Inclusions in St.Faith's granite softened and flattened out parallel to the foliation plane (site 10C).

Umzimkulu Valley and the interior plateau which the writer considers to be part of the landsurface produced by the late-Cainozoic planation. The granite crops out along the St. Faith's road and occasional buttocks on the low rolling hillsides can be seen to extend towards Mehlomanyama and St. Faith's Mission Station.

Structure

The granite bodies are separate but linearly arranged in a WNW-ENE direction as seen on the geological map. This direction is parallel to the strike of the foliation within each body. The foliation dips 50° to 60° towards the SSW. These bodies are considered to have been separated to a large extent by the intrusion of the fine-grained Westlands granite. Intrusion also took place along the foliation of the St. Faith's granite in which case the fine-grained granite becomes indistinguishable from the St. Faith's aplitic dykes associated with late stage movement during consolidation. Pegmatitic dykes from later coarsely porphyritic Buffalo Bill granite intruded and cut across the foliation (Plate XIII, ph 1). Inclusions of amphibolite and gabbro are frequently found in this granite and show varying degrees of assimilation.

Texture and Mineralogy

The reddish to buff-coloured granite has a groundmass grain size of about 2 - 5 mm and pinkish insets of potash feldspar which vary from 1 - 5 (average 1,44) cm in diameter.

A macrometric analysis yielded the following average

volumetric/

volumetric mode for this granite:-

K-felspar	34,7%
plagioclase	24,5%
quartz	29,5%
biotite (+ dark minerals)	11,3%

In places this granite is a distinct "augen gneiss" with rounded drawn-out feldspars reminiscent of a typical porphyroblastic texture. The porphyroblastic texture is found along zones of movement or greater mobility forming a mush of K-feldspar insets. This looks similar to the Bulai granite of Messina, Transvaal, and the Porphyritic Granite associated with the Chibi batholith described by I.D.M. Robertson at the Granite '71 Symposium in Salisbury.

The formation of the mush of K-feldspar in the St. Faith's granite is ascribed to prolonged consolidation with slow crystallization. Readjustment of the magma during movement led to resorption and repair, hence the typical texture. The postulated movement is evidenced by a late-stage aplitic phase which developed from residual fluids. The aplites locally cut across and incorporate the crystal mush of K-feldspar indicating the plasticity of the material during the closing stages of consolidation (Plate XIII, ph 2). In places the aplites merged with the surrounding granite. In other areas to the east where the granite has suffered less preconsolidation movement the phenocrysts retained their original shapes.

Inclusions of dark basement rock flattened by late movements support the above explanation of the pronounced

porphyroblastic/

porphyroblastic texture (Plate XIII, ph 3). The shape of the dark inclusion in the photograph is of particular interest with regard to the mobility of Al in a solid phase; this being so limited that even in a softened-up state in a granite magma the inclusion is retained as a discrete body often forming a rim of minerals on the outside which are in equilibrium with the surrounding magmatic conditions.

(d) Westlands Granite

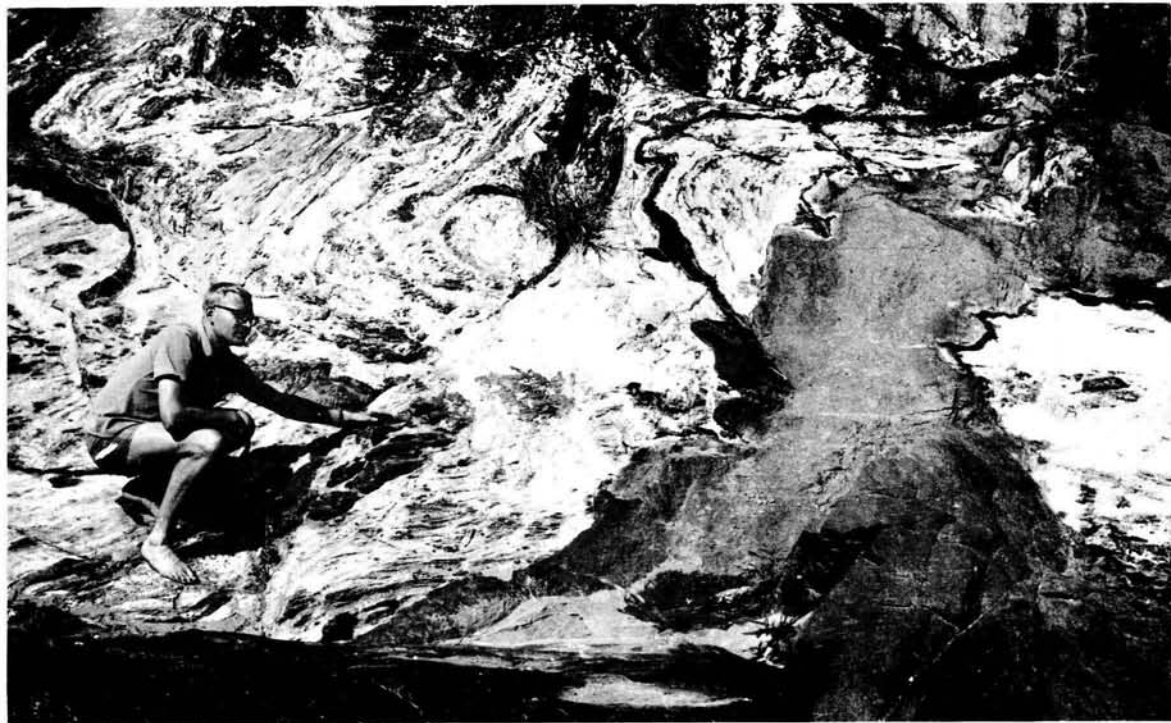
Field Occurrence

Large exposures of reddish fine-grained (almost aplitic) granite occur in the northern part of the Marble Delta. The type area is near the northern corner beacon of the farm Westlands. A number of outcrops lower down the hillside are correlated with this granite, as well as the large dyke-like bodies occurring in the south-east towards and on The Vineyard. The fine-grained granite which intruded the St. Faith's granite is also correlated with the Westlands granite.

Age Relationships

The correlation of these fine-grained granite bodies with outliers elsewhere in the Marble Delta and with the fine-grained dykes will remain in doubt until detailed mineralogical studies and age determinations have been made. However, apophyses of the Westlands granite intruded as dykes into the marble and cut across folded structures (Plate XIV, ph 1). In the densely wooded gulleys on Westlands there

are/



Ph 1. Apophysis of Westland granite cutting across a fold in the marble with an offshoot which follows the outline of the fold and thus postdates the main structural deformation. The direction of plunge of linear calc-silicate aggregates is pointed out by the person in the photograph.



Ph 2. Dismembered fine-grained granite dykelet in calcite marble. Note the difference between original contact zone and broken edges where wollastonite formed as a result of induced contact metamorphism by a later granite intrusion.

are places where the coarsely porphyritic Buffalo Bill granite intruded along a full set of joints present in the fine-grained granite. On N'Dongeni this granite also cuts across the lineation of hornblende-pyroxene gabbro.

Structure

The massive outcrops on Westlands have no clearly visible structures, but in the densely wooded area faint "flow-lines" stand out on the weathered surface. These may possibly represent a foliation outlining the shape of the body since they are parallel to the surrounding metasediments and amphibolites as seen on The Vineyard. Along the St. Faith's road and on The Watershed the abovementioned "flow-lines" are also prominent and the intrusion is in places controlled by the structure of the St. Faith's granite. On Buffalo Bill a massive outcrop of similar-looking granite shows that the banding or foliation dips 30° to the south. Microscopic examination of these ribs or "flow-lines" due to differential weathering, reveals no mineralogical difference except possibly a slight increase in feldspar content.

A number of gneissose amphibolitic rafts are enclosed by this granite on the northern part of Westlands; towards Cherrywillingham Park the inclusions increase in abundance.

Texture and Mineralogy

The average grain size is 1 mm, becoming coarser and more varied towards Buffalo Bill. On Westlands the texture is equigranular with plagioclase, microcline and quartz as principal constituents. The granite becomes finergrained

further/

further west on Buffalo Bill with an average grain size of 0,8 mm. The volumetric mode of this granite at site 5D 2342 is:

microcline-microperthite	59,8%
plagioclase	12,2%
quartz	24,4%
biotite	3,0%
pyrite	0,6%

The microcline-microperthite is evenly distributed and exhibits grid-iron twinning and strained patterns with a large amount of orientated perthitic exsolution lamellae and stringers. The $150\bar{2}$ exsolution lamellae indicative of magmatic crystallization of K-felspar phenocrysts (Otto, 1957) were not found to be present so all the K-felspar probably crystallized during the late phase of consolidation, hence the even-grained texture. Myrmekitic intergrowths support the above suggestion and also indicate that the fine-grained texture is not a result of rapid chilling but probably due to especially dry conditions.

The plagioclase contains exceedingly fine and tapered twin lamellae showing that the granite was subjected to deformation. Some plagioclase grains slightly clouded with dust particles also have rims of clear unaltered plagioclase.

Green and straw-yellow biotite is characteristic of this granite. Biotite has been extensively altered to sericite and chlorite at some localities.

(e) Umzimkulwana Granite

The type locality of this fine-grained granite where it is best exposed is along the tract of the Umzimkulwana River about 500 metres downstream from the causeway on Simuma. The only structure noticeable along the river is a faint flow banding with a 20° dip to the south-west. The granite separates the main mass of marble from the southern outcrops. It is tentatively correlated with similar looking granites to the north in the Umzimkulu Valley and perhaps with the Westlands granite, but a correlation with the St. Helen's Rock granite is not ruled out. Outliers of the Umzimkulwana granite are found in the Lynwood area and close to the southwestern corner beacon of Simuma. They are intruded by the porphyritic Oribi Gorge granites and occur as roof pendants within the latter.

Along the Umzimkulwana River coarse pegmatitic and granitic dykes are present in this granite. It also contains irregular patches of fine-grained granite (site 6P 432), characterized by indistinct boundaries with a slightly coarser type, suggesting auto-injection during emplacement. This granite is not gneissose at all and does not have a porphyritic texture except for an occasional inset of microcline or an irregular pegmatitic trail of potash feldspar and garnet.

(f) Oribi Gorge Granites and Charnockitic Rocks

Simpson and Tregidga (1956) described the granites in the southwestern corner of the area as predominantly porphyritic gneiss (the so-called "Western gneisses") followed further west by the Oribi Gorge granites. The latter crop out along the Oribi Gorge in the Umzimkulwana Valley and consist of "grey biotite gneiss bands interleaved with charnockitic rocks". Simpson and Tregidga (1956) gave a good petrological account and chemical analyses of four typical representatives of the charnockitic suite, namely charnockitic granodiorite, biotite granulite, fayalite-augite granodiorite and charnockitic adamellite.

The "western gneisses" are in fact composed of several different granites which are more or less gneissose in certain localities. The main component is a coarsely porphyritic granite which is intrusive into The Wolds and Umzimkulwana fine-grained granites. The main mass of porphyritic granite west of the marble and amphibolite may perhaps be correlated with the Buffalo Bill granite. In places the porphyritic granite has a flow structure (which may be called a gneissosity) where potash felspar blastites formed during the final consolidation stage. The potash felspar phenocrysts and blastites vary from deep red to green similar to those of the charnockitic rocks further upstream and of the Buffalo Bill granite. There is further a distinct reduction in phenocryst size and matrix grain size from west to east. Averages were measured as follows:

	<u>Phenocrysts</u>	<u>Matrix</u>
	(cm)	(cm)
1 500 metres west of marble	3,8	0,95
1 000 metres west of marble	3,2	0,7
100 metres from marble (6S 3221)	2,5	0,5

Garnet is present in nests associated with biotite. This is the only important difference between the Oribi Gorge and Buffalo Bill granites.

(g) Buffalo Bill Granite

In the northwestern part of the Marble Delta on Buffalo Bill and Oribi Flats a coarsely porphyritic granite forms massive outcrops along the Umzimkulu Valley. This is where the Umzimkulu narrows and forms a series of fast rapids towards the contact between the marble and the granite. On both sides of the valley the Buffalo Bill granite is capped by Table Mountain Sandstone. Outcrops are also present along the Renkin fault and scattered outcrops further east within the marble area are also correlated with this granite.

Age relationships

This granite is the parent intrusion of numerous apophyses cutting across The Wolds, St. Faith's and Westlands granites as well as the marble formations. It represents one of the last granitic intrusions in the area. The relationship of this granite with the Oribi Gorge granite is not known.

Structure and emplacement

The outcrops along the river appear massive without any prominent gneissosity like that which the Oribi Gorge granite shows in places. According to the structural attitude of the large dyke described below and numerous other bodies on Le Jonquet it appears as if these intrusions were mainly emplaced from the north-west. The fact that the granite also intruded along a set of joint planes in the Westlands granite (Map 1, 13H) suggests shallow emplacement as compared with the earlier granite. This granite furthermore cuts across secondary folds in the marble which contains dismembered dykes of fine-grained granite.

Mineralogy and Texture

Like the Oribi Gorge granites the Buffalo Bill granite consists of large pinkish to red areas with patches of grey granite. There is a considerable variation in the microcline phenocryst sizes. They may be up to several centimetres in diameter and are often rounded and pink with a white rim of plagioclase (usually oligoclase). This colour contrast readily lends itself to macroscopic modal analyses of these exceptionally coarse-grained rocks in the field. In the grey Buffalo Bill granite the plagioclase is also distinguishable from the grey potash feldspar. A locality along the river about 200 metres west of LC 1331 was chosen for this purpose and the results are recorded in table 8 together with those of the dyke-like body to be described.

Table 8: Macrometric modes of Buffalo Bill granite

(vol. per cent)

	<u>Microcl.</u>	<u>Plag.</u>	<u>Quartz</u>	<u>Hbl + Biotite</u>
1 Red porphyritic granite	59,1	18,3	12,9	9,7
2 Red porphyritic granite	64	15	15	6
3 Grey porphyritic granite	60	9	27	4
4 Granite dyke-The Watershed	38,5	16,2	39,7	5,6
5 Granite dyke-East Slopes	43,6	19,1	26,2	11,1

(h) Granite dykes

Several ages of granite gave rise to a profusion of dykes and irregular intrusive bodies criss-crossing the Marble Delta in a haphazard manner. Not only was each intrusion modified by assimilation but different paths of crystallization with respect to their parent or even adjacent related bodies were followed under changing equilibrium conditions. The majority of intrusions originated from the Buffalo Bill granite. Older fine-grained dykes and a few soda-rich ones (oligoclasite) are also present. The mineralogy and petrology of all the intrusives in the Marble Delta deserve further study as new quarries continuously reveal the presence of different rock types and reaction zones associated with them. A few examples will be discussed.

i. Great dyke of Buffalo Bill granite

The central part of the Marble Delta is dominated by a large dyke-like intrusion which was partly mapped by Du Toit (1918). All the other dykes indicated by Du Toit (1946)

are/

are purely diagrammatic and cannot be located in the field. The granite crops out on the hillsides of The Watershed and Westlands, crosses the Umzimkulu River and ends abruptly on West Slopes. In plan the outcrop is curved, suggesting a southwesterly dip. This is confirmed by the large flesh-coloured platy phenocrysts, forming a foliation which dips 60° to the south-west. On top of the hill on East Slopes the dyke encloses rafts of dolomite marble as well as blocks of quartzite and amphibolite.

Numerous offshoots from this dyke-like body into the marble consist almost wholly of potash felspar intergrown with quartz. The dyke is correlated with the Buffalo Bill granite because it is joined to the latter by such offshoots and because it displays the same coarse texture and microcline phenocrysts.

The granite is reddish and has a groundmass grainsize varying from 1 - 2 cm in the central area. The phenocrysts are oval or rounded in shape and range in size from 6 - 9 cm. Platy phenocrysts up to 6 cm in length and 2 cm in width have been found. In places the phenocrysts are scattered suggesting turbulent flow, but usually they are distinctly orientated. The volume of phenocrysts diminishes towards the top of East Slopes hill and towards the east indicating an influx from a deepseated source located in the north-west. The most easterly outcrop on West Slopes also contains the largest phenocrysts (15 cm in length). In the latter area the dyke developed its own aplitic segregations parallel to the foliation. The aplite also grades into pegmatitic

segregations which contain garnet clusters in places.

The modal analyses (Table 8, Nos. 4 and 5) carried out in the field on The Watershed and East Slopes, show a considerable increase of quartz over microcline compared with the parent Buffalo Bill intrusion. However, on the south bank of the river at LOM contamination by basic rocks is evident from the darker appearance of the granite and the presence of rounded xenoliths.

ii. Coarse-grained granite dykes

The greatest ramification of granite intrusions apart from the dyke described above is on Le Joncquet. These irregular bodies and dykes cut through calcite marble and continue to the north-west, south and east. They are probably all connected with the Buffalo Bill granite and those on Umdwendwa and Lot F 0 as well. The dykes on Simuma and The Forest contain garnets and are correlated with the Oribi Gorge granites.

The apophyses from the Buffalo Bill granite not only injected in a lit-par-lit fashion along relic bedding, but also as irregular bodies and dykes some of which pinch out in a vertical section (Plate XV). This type of abrupt termination is also seen in the horizontal plane as indicated by the intrusion pattern of the granite on a geological map (Map 2). The sub-parallel dykes thin out southwards from a few metres in width to a few millimetres, i.e. smaller than the calcite grains in the marble.

The overall pattern is indicative of a waning stage of

granite/

granite intrusion. The cessation of intrusive activity gave rise to the arrestation of metamorphic reactions which produced the disequilibrium mineral assemblages of the induced skarns. As these reactions took place under closed system conditions of high P_{CO_2} , the mineral assemblages associated with the granite dykes afford an excellent field for petrological studies akin to experimental petrology.

Structure

The dyke walls sometimes show linear features ("ripples") which coincide with the plunge (45° S.W.) of the lineation in the amphibolite and the directional fabric of the marble on Le Joncquet. In some cases this is due to adaptation of the dyke to pre-existing structures in the marble, while elsewhere the contortions must be ascribed to the plasticity acquired by the marble at the time of intrusion. The latter type of deformation is corroborated by the dismemberment of earlier fine-grained granite dykes occurring as scattered angular blocks as though they had been mechanically mixed with the calcite marble (Plate XIV, ph 2). The earlier dykes in the marble follow joint planes whereas the later coarse-grained dykes mostly intruded along relic bedding planes thus indicating the relative age and geological level of emplacement.

In places the granite also shows multiple intrusion. For example on 165 Level a 15 cm wide auto-injection stripped the green reaction selvage from the wall-rock and pushed it to the inside of the dyke. This later influx can only

be recognised by the thin sliver of contact minerals and the slightly more brownish shade due to a higher X_{H_2O} . The retention of such a delicate screen, the predominantly unstrained microcline and quartz and the absence of protoclastic deformation indicate that the process of injection was essentially passive.

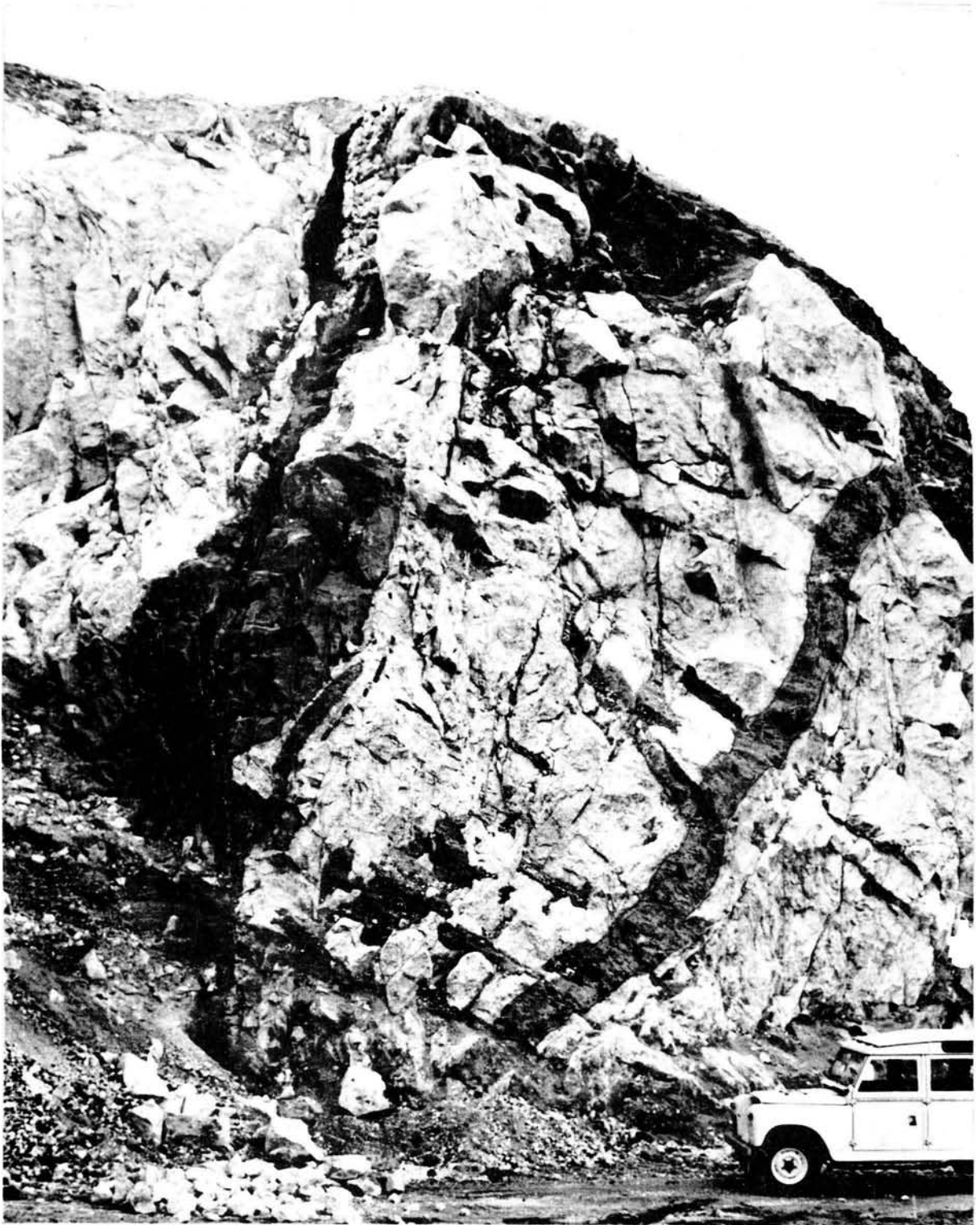
The development of undulating dyke walls up to tens of metres in amplitude (of which the initial stage is illustrated in Plate XV), ptigmatic folds in granite dykelets and structures resembling boudinage are more fully dealt with under Structural Geology.

Texture

Although most of the dykes can be described as coarse-grained, the texture varies considerably from one body to another. A detailed account of one particular dyke at O 238 which thins out over 130 m to a thickness of a few mm has been given elsewhere (Otto, 1972). Phenocrysts of microcline (6 x 4 cms) are not readily distinguished from the coarse-grained groundmass and are not present in all the bodies. Some of the dykes contain coarse intergrowths of microcline and quartz reminiscent of pegmatites. The microcline which is usually pink in the Buffalo Bill granite is green in the smaller dykes and snow-white in dykelets. The greenish to black clinopyroxene stands out against the buff to grey granite and differs clearly from the dark minerals along the contact selvage.

In calcite marble the contact selvage is usually narrow

compared/



Photograph of Calcite Quarry face on 165 Level (Map 2) showing a blind intrusion of granite with a minor blind dyke just beneath it. Note the dismembered amphibole dykelet in the calcite marble immediately below and the vertical Karroo dolerite dyke cutting across the upper intrusion. On the right hand side is a granite dyke of the same period of intrusion but of slightly earlier age. It is in parts conformable with relic bedding of the marble and shows incipient folding due to increased ductility of the marble immediately adjacent to the dyke as a result of magmatic heat. (Northward view).

compared with the reaction zone in dolomite marble consisting of humite group minerals, forsterite and phlogopite. The width of the reaction zone bears no relation to the width of the dyke but rather to the distance from the parent body of granite. Thus a 1 cm dykelet will have the same contact reaction zone as the nearby granite to which it is attached. In the case of tapering dykes far from the main centre of intrusion a series of mineral assemblages is present. One example is summarized in Table 9.

Quartz

The faint bluish hue and greasy-looking lustre of quartz in some of the intrusions is of special significance when compared with the quartz typical of charnockitic rocks. All essential minerals in these rocks are remarkably clear and free of hydration. A possible explanation of the quartz hue may therefore be sought in generally dry conditions or high P_{CO_2} during crystallization. Quartz forms concentrations where the dyke wall becomes irregular and also gives rise to dykelets or offshoots consisting of quartz only. Wollastonite is found in places where the quartz peters out or where the X_{H_2O} is assumed to have increased considerably in the deuteritic phase.

Microcline-microperthite

In the large Buffalo Bill granite dykes the microcline is pink to flesh-coloured but it becomes grey to greenish in thinner dykes and white when isolated in wall-rock. From the parent body outwards along the dyke the microcline exhibits a serial variation in triclinicity (Otto, 1972)

and/

COMPARATIVE SUMMARY OF MINERALS RELATED TO DYKE-WIDTH

TEXTURE (groundmass)	PORPHYRITIC (30-15 mm)	PEGMATOIDAL (3 mm) (2 mm)		DOMINANTLY INTERGROWTHS and MYRMEKITIC TEXTURES (0.8 mm)
DYKE CORE	(Chlorite Zircon Sphene Rutile)	QUARTZ		QUARTZ
	QUARTZ	MICROCLINE (cross-hatch)		White MICROCLINE (cross-hatch)
	MICROCLINE (1502)	CLINOPYROXENES 2V γ 80		
	CLINOPYROXENE (Hedenbergite)	2V γ 58-60		
	Brown hornblende Oligoclase Andesine	Hornblende	Green hornblende	
REACTION ZONE	(OLIGOCCLASE) (QUARTZ)	OLIGOCCLASE and ANDESINE QUARTZ		WHITE MICA PLAG - CPX - intergrowths (Phlogopite)
CONTACT ZONE	QUARTZ DIOPSIDE (+1 mm)	QUARTZ DIOPSIDE (0.3 mm) (Sphene) Zoisite Clinozoisite	(QUARTZ) DIOPSIDE (0.3 mm) (Sphene)	(MIZZONITE) TREMOLITE DIOPSIDE (0.3 mm) WOLLASTONITE
DYKE-WIDTH	640 mm	80 mm	50 mm	15 mm 7 mm

TABLE 9.

(After Otto, 1972)

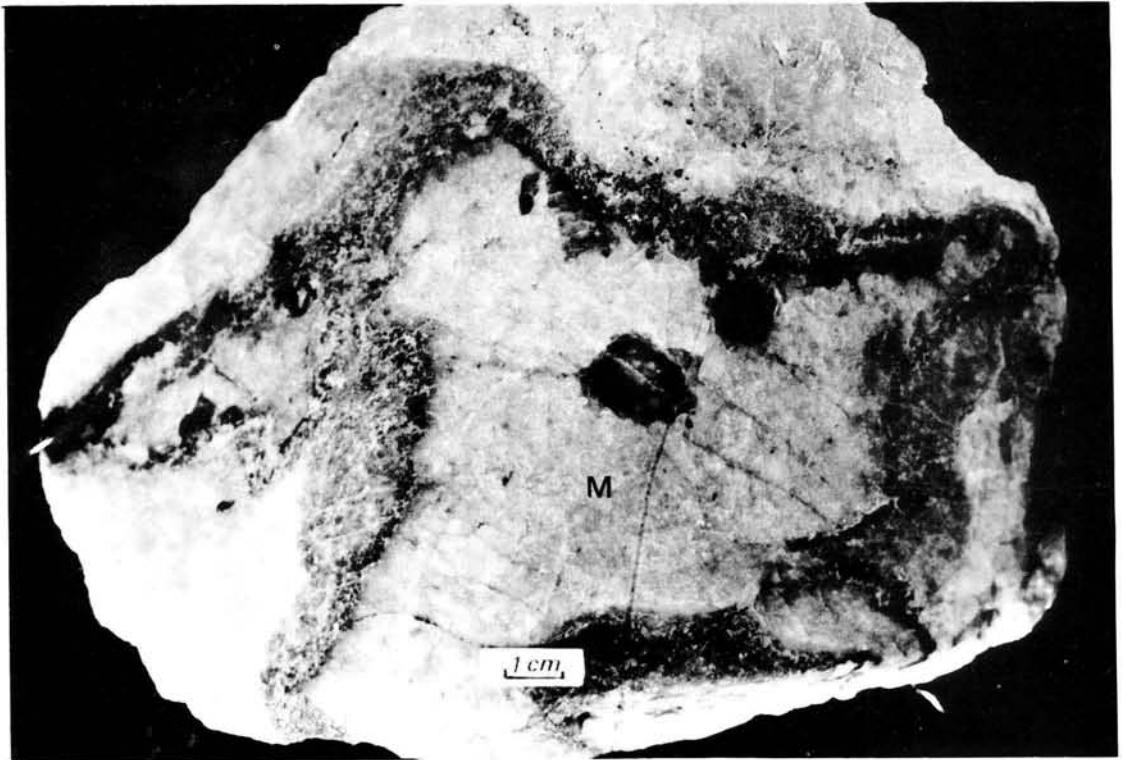
and attains almost maximum microcline in the thin parts of the dyke. The pinkish microcline in closed-off boudins of deuteritic zones has a triclinicity of 0,91. These deuteritic assemblages (Plate XVI, ph 1) are preserved a short distance (cms) from the parent intrusion or other high temperature dykelets of microcline with clinopyroxene (Plate XX, ph 1). In any other country rock (e.g. gneiss terrain) this microcline would normally be interpreted as "sweated out", the result of replacement, enrichment, minimum melting, migmatization, hydrothermal alteration, etc. It is clear from the observations that in a semi-closed system, the order-disorder of (Al, Si) ions in potash feldspar is coupled to the temperature gradient.

Typical crosshatching of microcline is better developed in the cooler parts of the dykes but some microcline shows (150 $\bar{2}$) exsolution in the wider parts. In the quartz porphyry dykes of Cape St. Martin (Otto, 1957) it was found that microcline with (150 $\bar{2}$) exsolution lamellae and variable obliquity crystallized from a plus 80% fluid while crosshatched microcline crystallized from the late aplitic differentiate.

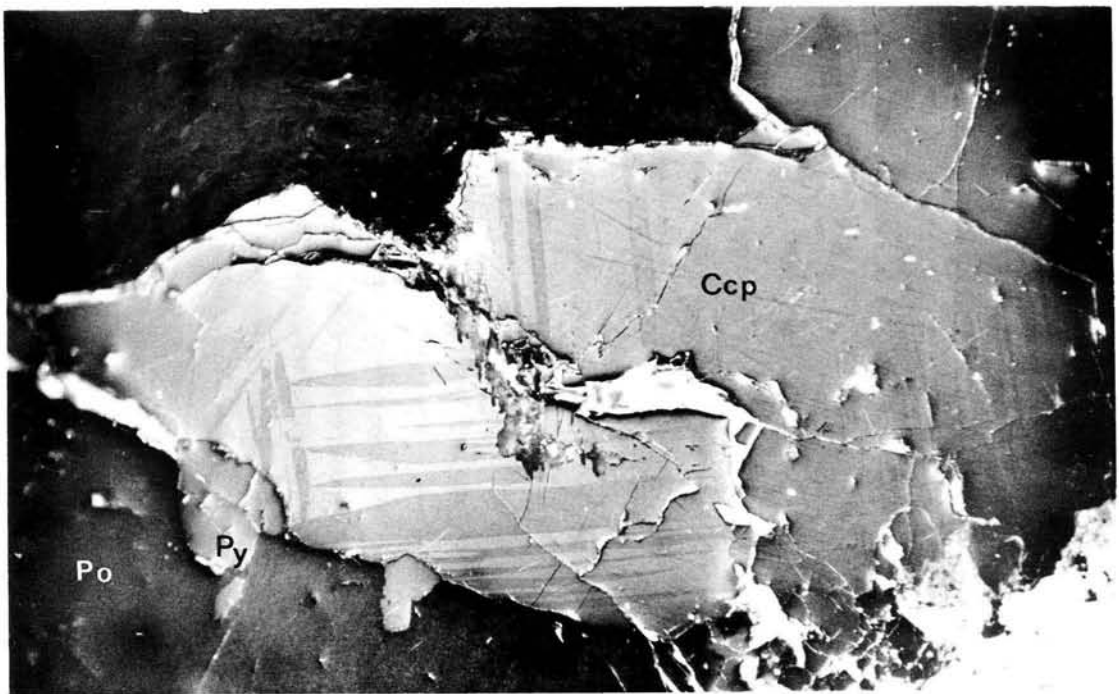
Myrmekite

This type of intergrowth is typical of charnockites and has been comprehensively reviewed by Spencer (1945), McIver (1963) and Hubbard (1966). All these authors

give/



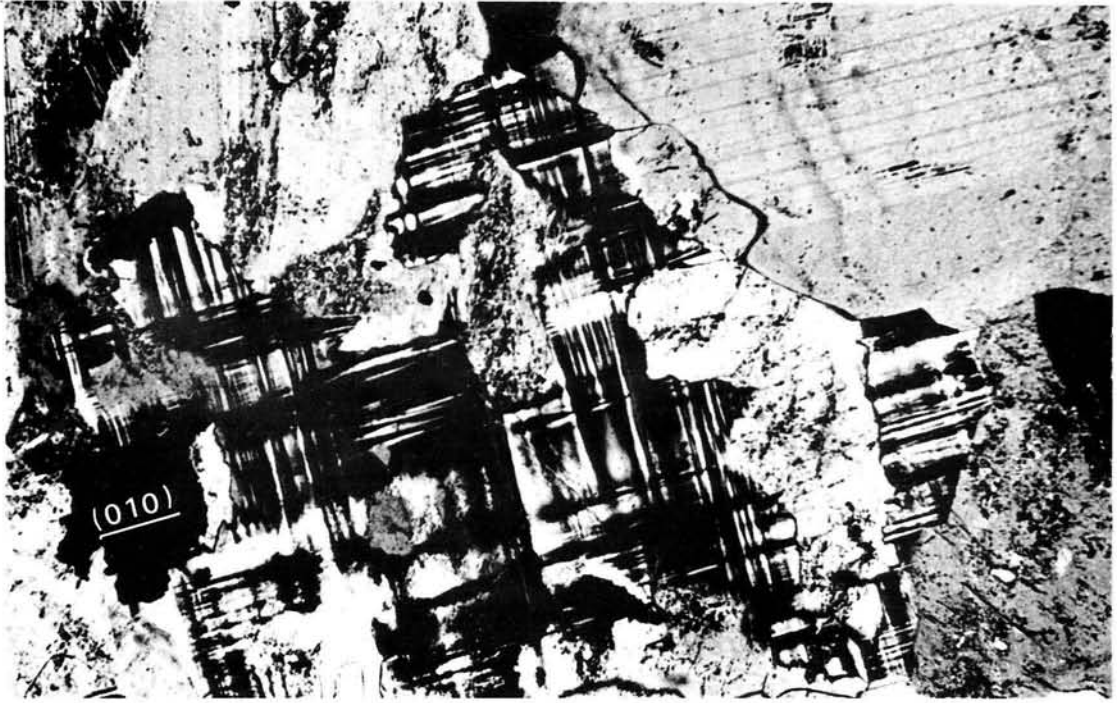
Ph 1. Irregular intrusion of microcline (M) representing a late magmatic stage of separation and forming a grey selvage (deuteric reaction, serpentine and sericite) with the calcite wall-rock. This is in contrast to the usual pyroxene or phlogopite contact selvage of nearby microcline dykelets.



Pm 2. Chalcopyrite (Ccp) associated with pyrrhotite (Po) and pyrite in calcite marble, showing both spindle-shaped and parallel twins. They are reminiscent of "oleander leaf" twinning indicating former high temperature chalcopyrite (Ramdohr 1969). Internal terminations distinguish deformation twins from parallel-sided twins which are the criteria for growth and annealing (Stanton, 1972). (Reflected polarized light, X100).

give preference to an origin by exsolution rather than replacement or simultaneous crystallization. However, certain features of the myrmekite in the granite dykes on Le Joncquet point towards a relationship with residual magmatic fluids and seem to be incompatible with exsolution. These features are the following:-

1. The myrmekites increase in abundance towards the thin end and marginal portions of the dykes.
2. Myrmekite was found to fill a corrosion channel in quartz, undoubtedly due to resorption at an early stage of crystallization of the magma (Plate XVIII, pm 2).
3. The intergrowths fan out from plagioclase and project into embayments of microcline, which may be likewise ascribed to resorption (Plate XVIII, pm 1 and 2).
4. Microcline selectively resorbed along the albite and pericline twin directions are also present without any myrmekite (Plate XVII, pm 1).
5. The worm-like quartz becomes thinner towards the resorbed microcline in a manner reminiscent of plantroots (Plate XVIII, pm 1 and 2). This is obviously a directional feature and may represent an arrested stage of the exchange reaction between microcline and fluid. However, Hubbard (1966) provides another explanation of similar textures observed by him.
6. Vermicular quartz is also found to extend over three adjacent plagioclase grains differing in orientation,



Pm 1. Embayed microcline present in 5 cm wide granite dykelet. Microcline was selectively resorbed along pericline and albite twin directions (010) shown on pm) which also suggests that repair must have taken place according to a triclinic configuration (crossed nicols, X115).



Pm 2. Resorbed calcite in a clinopyroxene phenocryst of a granite dykelet which intruded the calcite marble. This represents the critical stage at which the calcite-quartz assemblage became a stable one in a magma under closed system conditions of high P_{CO_2} . (Site P 240, ordinary light, X115).



Pm 1. Photomicrograph showing root-like myrmekite extending from plagioclase on the left to microcline with resorbed outline. Synantetic growths of hornblende and quartz where clinopyroxene is in contact with microcline. (Granite dyke, 165 Level, Calcite Quarry, crossed nicols, X65).



Pm 2. Photomicrograph of myrmekite which developed in a corrosion channel of a single quartz grain filled with microcline. Note optical continuity of quartz and apparent alignment of fluid inclusions (crossed nicols, X60).

with no obvious relationship towards K-felspar from which it was supposed to exsolve.

These observations appear to favour a segregation of quartz and may help to explain why silica separated as a fluid from the same magma and intruded the wall-rock in the form of dykelets.

It should perhaps be emphasized that such textures were not observed in the parent body from which the granite dykes emanate. The preservation of evidence for resorption may be due to specialised conditions within the dykes (relatively slow cooling, isolation of residual liquids, build-up of high P_{CO_2}). Whether the observations may be extended to explain the origin of myrmekite in quartz-bearing rocks in general remains an open question.

Plagioclase

Plagioclase usually concentrates towards the contacts where the granite thins out and shows normal continuous zoning (An_{35-25}) even when present next to corroded calcite crystals. Plagioclase may also rim microcline in the thinner parts of the dykes. In this case the plagioclase is later as it also forms rims around cracked and altered plagioclase. The An content may vary from 15 to 35 per cent with a preponderance of the plagioclase in the $An_{25} - An_{30}$ (2V α 86 - 2V γ 89) range. Serial variation of the anorthite content was not observed along the length of the dykes. The twin laws commonly encountered were the Ala B and Ala A and/or Manebach Acline. In certain suitably cut

thin/

thin sections where the α 's plotted together on the stereogram and complete extinction was observed on the Fedorov stage, it is possible to distinguish the parallel twin from the complex twin.

Clinopyroxene

Large pyroxene insets (up to 10 cms) developed in the dykes where they emerge from the parent bodies. Even larger crystals (20 cm) separated out along the contact of the main forked granite intrusion on Le Joncquet (J 229). In hand-specimen the typical metalloid lustre of diallage may be seen on the (100) parting. The clinopyroxene is greenish black with perfect (100) (001) and (010) partings. Variation in chemical composition from hedenbergite to augitic pyroxenes was found by partial analyses and determination of optical characteristics. The variation depends on dyke-width and cooling history (Table 9, fig. 5). Resorbed black chlorite is often found in the clinopyroxene of up to 1 cm in diameter. The corroded outline of chlorite seems to indicate that it crystallized before the clinopyroxene and was fortuitously preserved in certain localities. According to experimental work on chlorite the stability field is within the temperature range of the dyke magma. Fawcett and Yoder (1966) found that the upper stability limits for magnesium chlorites are as high as 830°C at 10 kb and that the quartz + chlorite assemblage co-exists up to 600°C and 2 kb.. Turnock (1960) found that iron does not reduce the maximum temperature of stability of chlorite + quartz assemblage.

Hornblende

Subhedral hornblende is occasionally found but more commonly it forms a rim around pyroxene insets. It may even line a protoclastic crack in clinopyroxene showing that it crystallized at a late stage. A variation in the angle between the C-axes of amphibole and pyroxene is also observed along the length of the granite dykes.

Petrogenesis

Figure 5 summarizes the course of crystallization of the dyke magma leading to different mineral parageneses under changing equilibrium conditions related to the distance from the parent intrusion and to reaction with the wall-rock. The reaction with the wall-rock stops when the P_{CO_2} increases to such an extent that the $CaCO_3 + SiO_2$ assemblage becomes a stable one. In fig. 5 it is indicated that microcline crystallized over a wide temperature range so that with continued intrusion some granite dykes and bodies will be more potash-rich than others. The crystallization of microcline starts early but it is also one of the last minerals to form. This would explain why K-felspar could be trapped in a semi-closed system sealed off by marble to form monomineralic dykelets. In schistose or gneiss terrains a great deal of the potash in a granite magma may be lost into the surrounding country rock through metasomatism. This microcline is then commonly regarded as "sweated out" instead of introduced but observations in the Marble Delta indicate that such interpretations are not necessarily correct.

DIAGRAMMATIC REPRESENTATION of MINERAL PARAGENESES of the DYKE MAGMA CRYSTALLIZING UNDER CHANGING EQUILIBRIUM CONDITIONS

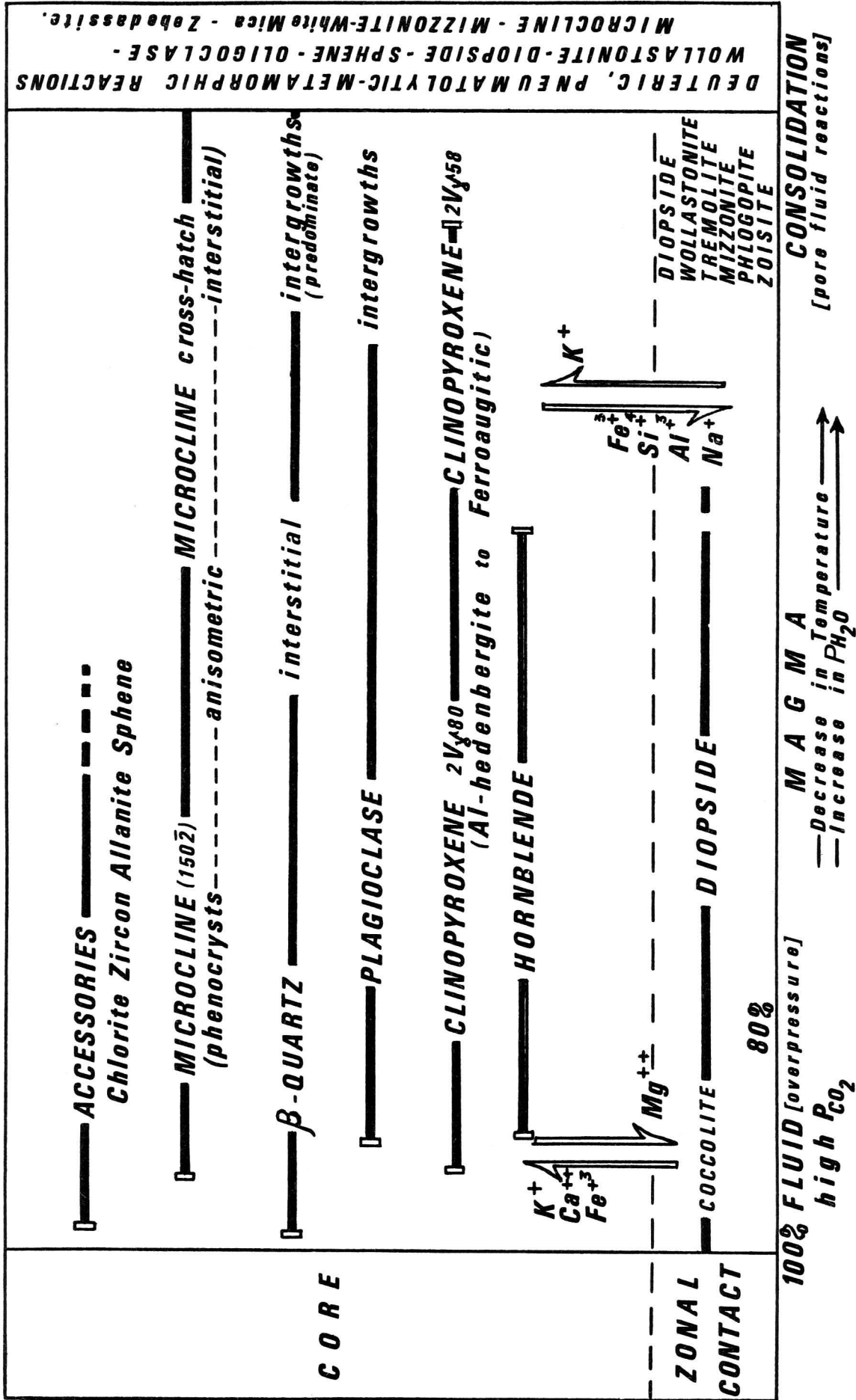


FIGURE 5.

(After Otto, 1972)

(i) Oligoclasite Aplite

Thin (20 cm) dykes and sheets consisting essentially of oligoclase occur in the dolomite marble on Le Jonquet (Map 3, Y 174). The grain size is 0,6 mm and the texture equigranular. The intrusions are not easily seen against the white marble background but are recognised by their slight offwhite colour and contact zones of colourless phlogopite. X-ray diffractograms of the latter are identical with those of the transparent phlogopite associated with white microcline dykelets. The phlogopite is usually separated from the plagioclase by a vermicular growth of diopside and scapolite.

Table 10: Chemical Analysis, Molecular Norm and Niggli Values

<u>of Oligoclasite</u>					
SiO ₂	63,4	Or	17,74	si	252,2
Al ₂ O ₃	21,54	Ab	66,64	al	48,73
Fe ₂ O ₃ }	0,16	An	9,67	fm	2,54
FeO		Ne	4,84	c	8,31
MgO	0,40	Ol	0,11	alk	40,42
CaO	2,0				
Na ₂ O	8,8	(Analysts: Anglo Alpha Lab., Roodepoort)			
K ₂ O	3,1				
H ₂ O ⁺	0,6				

The oligoclasite could possibly have originated from the fine-grained Westlands granite which, by the process of desilication resulted in slight undersaturation as revealed by normative nepheline. A substantial loss of potash could

have occurred during the contact reaction which produced phlogopite. Dark fine-grained granitic intrusions (equated with the Westlands granite) are present on the 76 Level about 300 metres south-east of the oligoclasite but have a lower $\text{Na}_2\text{O}/\text{K}_2\text{O}$ ratio ($\text{Na}_2\text{O} = 5,05\%$, $\text{K}_2\text{O} = 4,05\%$). However, the possibility that the oligoclasite intrusions may have been associated with the N'Dongeni alkaline bodies should not be excluded.

(j) Monomineralic dykelets related to granite

A number of rather peculiar monomineralic dykelets are present in the marbles and because of their origin under special conditions they are discussed separately.

The term dykelet is used in the sense of the A.G.I. Glossary (1966) namely, a small offshoot or apophysis from a dyke. In such a definition it is implied that all the material was introduced at the same time and that it consolidated in place, as opposed to a veinlet which was emplaced by encrustation from the side walls of the fissure or by precipitation from watery solutions, metasomatic fluids or vapour. The definition given by Holmes for a vein (or veinlet) appears unsatisfactory: "An irregular sinuous igneous injection, or tabular body of rock formed by deposition from solutions rich in water or other volatile substances." Some dykelets in the Marble Delta, being sinuous and irregular may fit the morphological part of the definition, but not the genetic part while scapolite dykelets would satisfy the genetic requirements, having originated by volatiles.

The ambiguities that may arise are best illustrated by scapolite which forms both veinlets and dykelets in the marble, but this distinction would be difficult to prove in any other rock type where gaseous transfer or diffusion through the wall-rock takes place.

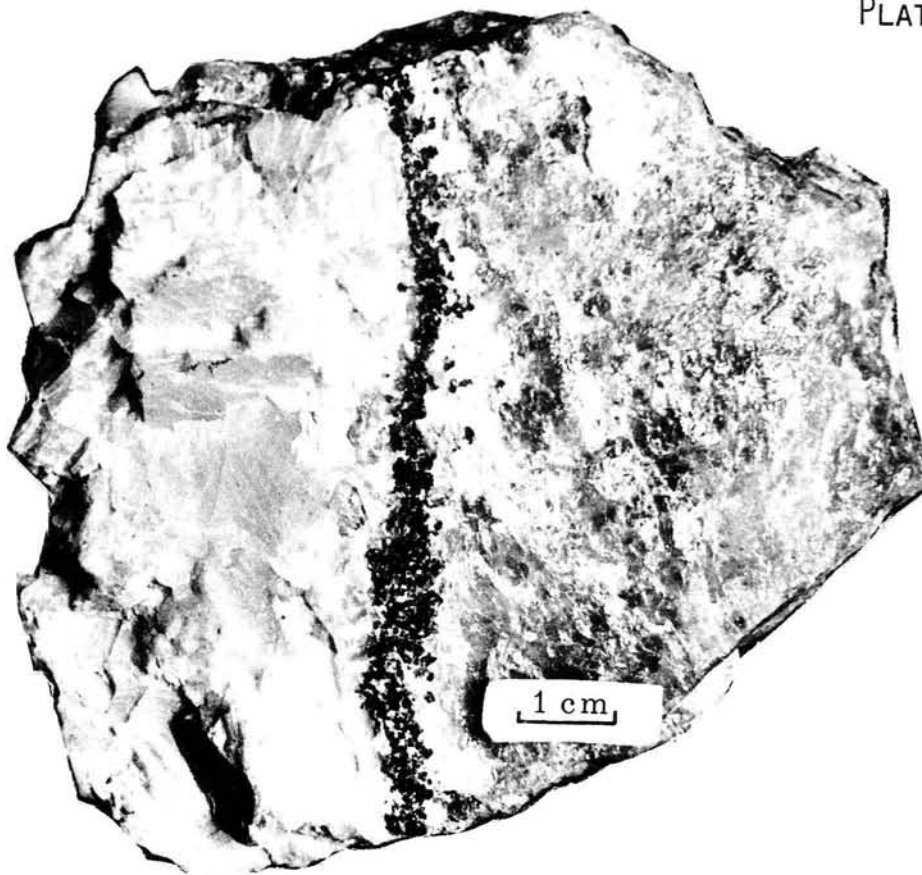
i. Quartz

Dykelets consisting almost wholly of quartz occur in the Le Joncquet area. They are associated with coarse granite intrusions in the calcite marble of the Oribi Formation. The dykelets vary from 2 to 10 cm in width and display their own reaction zones with the calcite wall-rock analogous to the reaction selvages of granite dykes (Plate XIX, ph 1). The slightly greasy lustre and faint bluish tinge of the quartz is similar to that of large patches, 15 cm across, which occasionally occupy the full width of a granite dyke, especially at places where a kink or pinch is present. These concentrations indicate that a quartz-rich fluid separated from the dyke magma and was injected into the calcite wall-rock which, at that stage of intrusion, formed part of a semi-closed system, preventing the escape of CO_2 and suppressing the formation of wollastonite. The configuration of the dykelets, which have structural features similar to those of granite dykelets (cf. Structural Geology), further indicates the ductile nature of the calcite wall-rock which underwent localised flowage. Wollastonite was found on the 165 Level on the contact of a 5 cm quartz dykelet (presumably due to a local concentration of H_2O during the closing stages of consolidation of the intrusion).

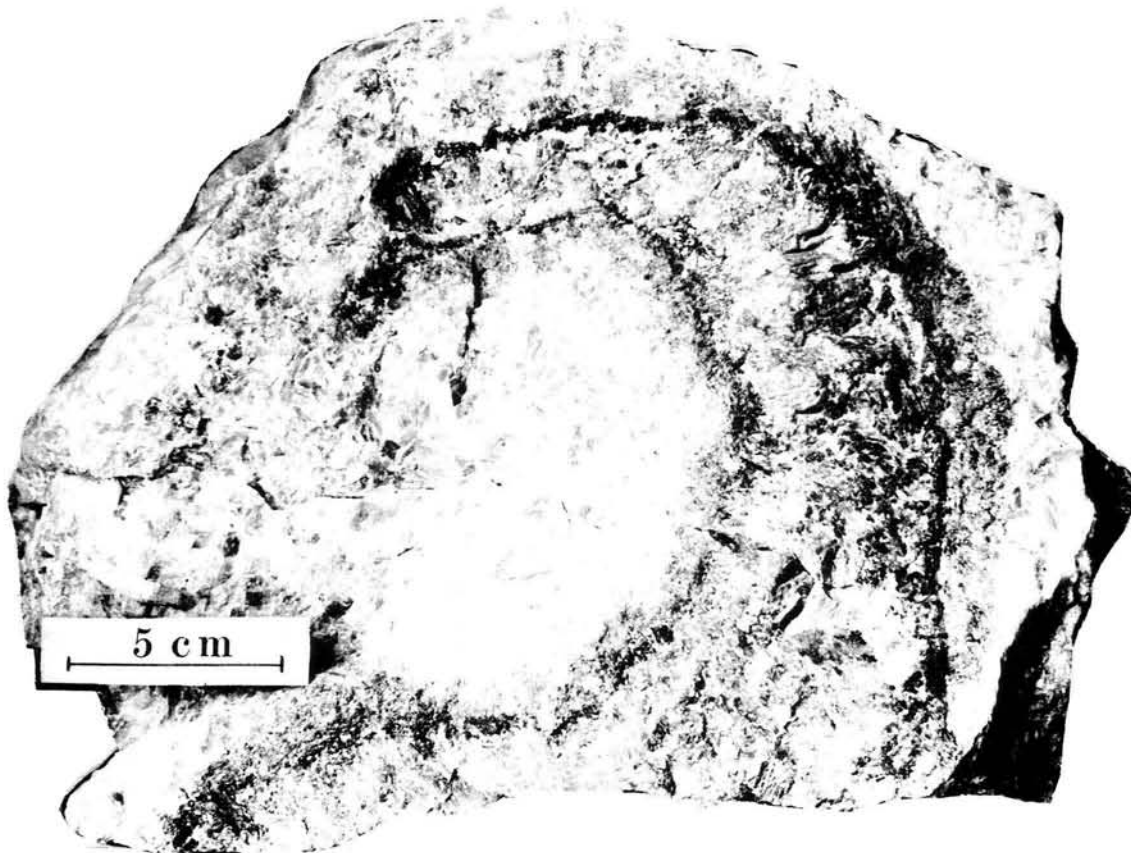
No quartz dykelets were found in the dolomite marble and are perhaps absent as a result of the greater reactivity of dolomite wall-rock as evidenced by the wide conskarn zone of forsterite, serpentine, chondrodite, clinohumite and clinopyroxenes. The decarbonatisation of the dolomite could take place because dissipation of the CO_2 was assisted by the unequal recrystallization of calcite and dolomite in the host rock which led to the opening up of the system along the dolomite grain boundaries.

ii. Microcline-microperthite

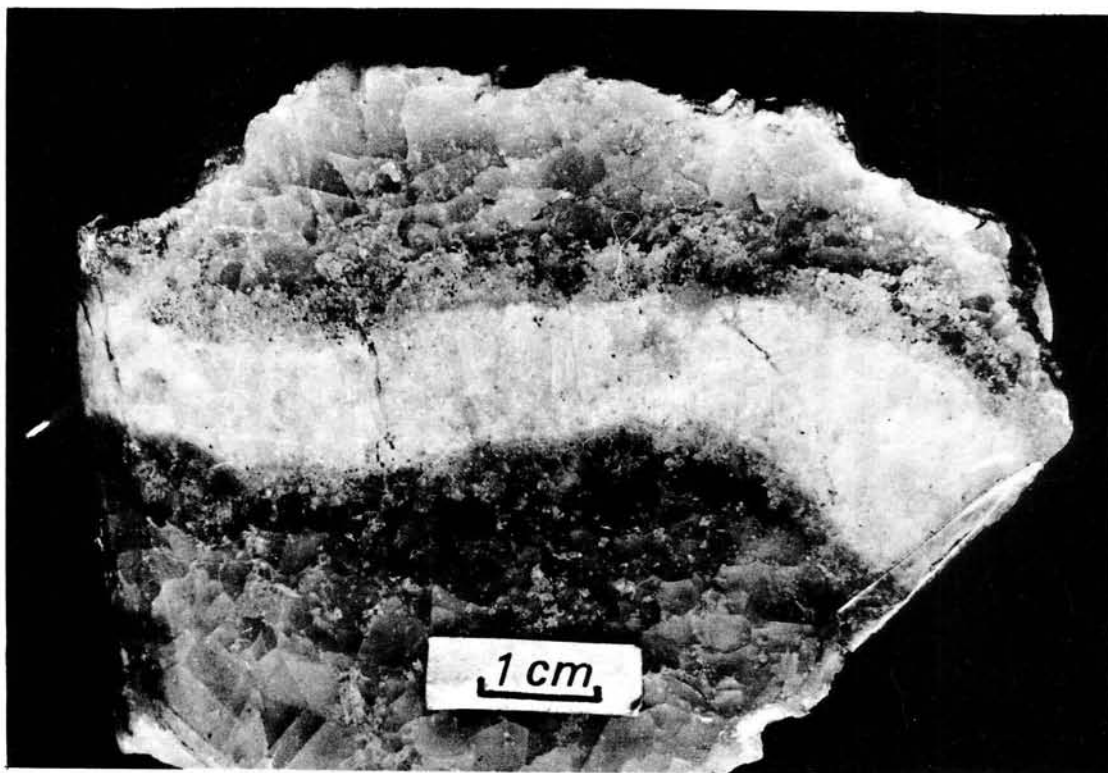
On the 165 and 130 Levels of the Calcite Quarries a number of microcline dykelets may be observed varying from 1 to 4 cm in width. They may consist wholly of microcline or may contain a small percentage of intergrown quartz or calcite. White microcline dykelets occurring on the 130 Level have a triclinicity of 0,99 and crystallized about one metre from a feeder dyke. The temperature of crystallization can be judged in the field from the contact reaction selvage from pyroxene to sericite and serpentine, the latter thus representing deuteritic stage dykelets (Plate XIX, ph 2). The microcline dykelets are closely associated with the quartz dykelets and were probably formed under similar conditions discussed above except that microcline is often segregated towards the centre of the granite dykes thus representing the last phase of crystallization. At this late stage some of the microcline offshoots may be completely trapped and isolated by flowage of marble until they finally



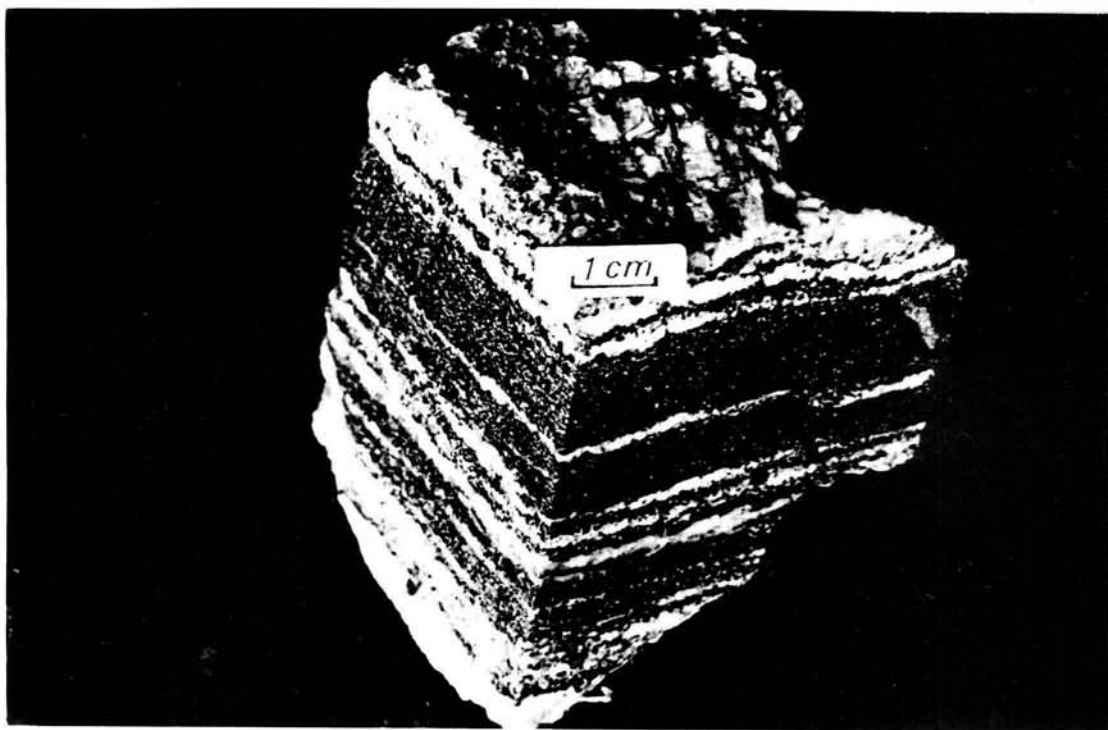
Ph 1. Fragment of quartz dykelet which emanated from a granite dyke. The quartz, like the parent granite, formed a green diopside reaction zone against calcite wall-rock. No wollastonite was formed due to the high P_{CO_2} .



Ph 2. Termination of a curved microcline intrusion with deuteric mineral assemblage forming a discoloured zone against calcite wall-rock.



Ph 1. Dykelet of white microcline with contact selvage of pyroxene and phlogopite against calcite wall-rock. (Alizarin-stained ground surface. Site O 239).



Ph 2. Retrokarn consisting of bands of calcite and transparent granular serpentine with magnetite and graphite inclusions. This is easily confused in the field with banded amphibolite.

consolidated at still lower temperatures of the deuteritic stage. Microcline, like quartz crystallized throughout the entire magmatic phase of crystallization and for this reason formed dykelets in the marble. They are not to be expected in permeable rock types.

iii. Scapolite

Scapolite is present in conskarns and metaskarns (Table 11). In the calcite marble at Le Joncquet evidence can be presented that scapolite also formed dykelets. They are called dykelets rather than veins because they are directly coupled with the feeder granite dykes and display the same boudinaged structure and ptigmatic type of folding as the granitic dykelets. The scapolite dykelets, which vary in width from a few mm to 5 cm, possess their own reaction selvage (conskarn) of phlogopite and diopside against calcite wall-rock. This is in contrast with the white and yellow scapolite which formed gash veins in the amphibolite. Scapolite often forms irregular, apparently isolated stringers in marble as seen in quarry faces without any apparent connection or continuation within the marble. However, on further advancement of the quarry face they are found to interconnect and link up with granite dykes that probably acted as feeders.

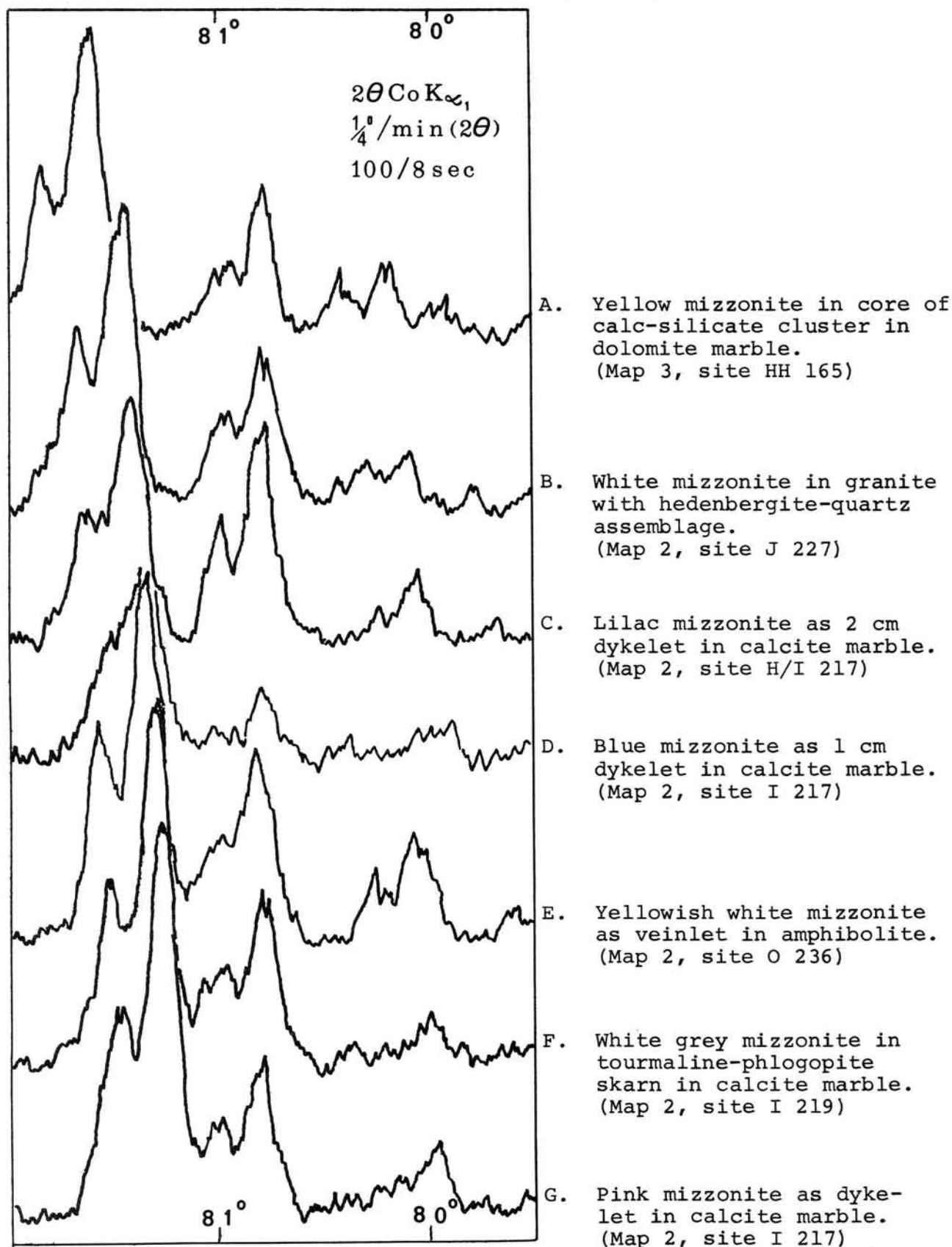
Greenish white scapolite crystallized with hedenbergite, quartz, allanite and microcline on the inside of a conskarn zone of the main granite body on 150 Level, site J 227. The scapolite is without any doubt connected with the off-

shoots from the abovementioned granite, which also led to the formation of metaskarn scapolite in secondary structures in the amphibolites. Such scapolite lacks the metamorphic contact selvages, thus demonstrating the transition from dykelets to metasomatic veinlets associated with a single phase of intrusion.

Because of this varied mode of occurrence, together with a considerable variation in colour from white to grey, yellow, greenish, lilac, pink and blue, a few samples were collected from the 130 Level for X-ray diffraction analyses. Burley (1961) observed that the measurable angular distance between reflection 400 and 112 of scapolite is related to the (percentage) meionite content. Peak separation measurements compared with Burley's results show that scapolite from Le Joncquet falls within the mizzonite range (50 - 80% Mei). The writer further found a distinct serial variation of the interval between the $2\theta_{325}$ and $2\theta_{751}$ peaks within this range (fig. 6). These data are compared with the peak separation of the 400 and 112 reflections:

	<u>$2\theta_{325} - 2\theta_{751}$</u>	<u>$2\theta_{400} - 2\theta_{112} (\text{CoK}_{\alpha_1})$</u>
A.	0,84	4,412
B.	0,69	4,381
C.	0,61	4,319
D.	0,55	4,312
E.	0,53	4,325
F.	0,51	4,300
G.	0,48	4,300

FIGURE 6. X-ray powder diffractograms showing angular variation in the parameter $2\theta_{325}-2\theta_{751}(\text{CoK}\alpha_1)$ of scapolites associated with Buffalo Bill granite dykes. (The increase in MeI content from B to G can be related to increasing distance from the granite).



It seems that the angular separation and, therefore, the composition of the scapolite is to a certain extent related to the distance from the granite or width of a scapolite dykelet. It corresponds to an increase of Ca as well as the CO_3 radical in the mizzonite structure. The change in the structural parameter is obviously caused by the change in both the chemical environment and the thermal history. The fact that mizzonite is present in the granite is probably due to the high P_{CO_2} under which the granite crystallized and this also seems to explain the peculiar formation of the dykelets. It may be predicted that, for this reason, the scapolite should show a low SO_4^{2-} content, as indicated by the late crystallization of pyrite and chalcopyrite which not only sought out intergranular skarn-mineral boundaries but also crystallized along cleavage planes of mizzonite.

In conclusion, the greyish green scapolite is considered to be magmatic; the lilac mauve and pink types are transitional from scapolite dykelets to hydrothermal veins and the white greasy to yellow type represents metasomatic scapolite veinlets.

V. SKARN

In the Marble Delta a wide variety of skarn-like rocks are found away from and at granite contacts. Some are due to metasomatism and others were formed by isochemical transformation. In some cases such an assemblage was produced indirectly; heat from a younger intrusive caused reaction between calcite or dolomite wall-rock and a pre-existing intrusive, e.g. amphibolite in the calcite marble. This latter process may be called induced contact metamorphism. Superimposed contact metamorphism may cause a single granite dyke to be accompanied by calc-silicates and related assemblages of several genetic types. A clear need is felt for a nomenclature capable of distinguishing between these different skarn-like parageneses.

1. Definition

"Skarn" is the old Swedish mining term for gangue material (pyroxene, amphibole, garnet etc.) associated with ore deposits in metamorphosed limestones (Holmes, 1920), but has been used extensively in the literature as a general connotation for contact metamorphic or analogous mineral assemblages in carbonate rocks. According to the AGI Glossary (1966): "The term is generally reserved for rocks composed nearly entirely of lime-bearing silicates and derived from nearly pure limestones and dolomites into which large amounts of Si, Al, Fe, and Mg have been introduced (after Turner, p.192, 1954)." Essentially the same definition was proposed by Hess (1919) for the term "tactite".

"Skarn" is the more widely used of the two terms and is favoured for that reason.

The above definition seems unnecessarily restrictive in that it excludes all instances where no addition of material took place. It suffers from the fact that a genetic meaning is implied (metasomatism) whereas evidence for other phenomena which were operative during skarn formation may exist in the field. The A.G.I. definition, by stating that large amounts of Al were introduced, becomes inapplicable in the Marble Delta, especially with regard to alumina originally contained in sediments. It has been found in the Marble Delta and shown in the literature (Carmichael, 1969) that Al is the least mobile constituent during metamorphism with a mobility which can be measured in millimetres. If metasomatic introduction of Al, Si, Fe and Mg is an essential part of the definition, the application of the term "skarn" becomes difficult in impure carbonate rocks.

It is, therefore, proposed that skarn should be used in a purely descriptive sense to include all the assemblages of metamorphic minerals in carbonate rocks that tend to form discrete bodies in marble, irrespective of whether metasomatism, flowage, recrystallization or any other action was the dominant process in their formation.

2. Classification

In order to accommodate the diversities at Marble Delta a genetic classification of skarns is presented here (Table 11). This classification is based on field evidence of genetic relations rather than chemical or mineralogical

characteristics/

PETROGENETIC CLASSIFICATION OF SKARNS OF THE MARBLE DELTA

GROUP	TYPE	BRIEF DESCRIPTION	EXAMPLES OF ASSEMBLAGES
I ISOSKARN	A INDUCED	Derived from pre-existing intrusive	Zoisite + plagioclase + pyroxene + hornblende (endomorphic)
	B NODULAR	Nodules or mineral clusters are zoned	Wollastonite + calcite (exomorphic)
	C BANDED	Reflects original bedding	Diopside + tremolite + graphite + calcite
II METASKARN	D TRANSITIONAL (ISOMETASKARN)	Contains minerals in disequilibrium	Diopside + forsterite + dolomite + spinel
	E METASOMATIC	Follows bedding and pre-existing intrusives	Mizzonite + diopside + forsterite + hedenbergite
	F TRANSITIONAL (METACONSKARN)	Near intrusives (contact metamorphism and metasomatism)	Clinohumite + forsterite + diopside + calcite
III CONSKARN	G CONTACT METAMORPHIC	Adjacent to intrusive	Chondrodite + clinohumite + forsterite
	H REACTIONAL	Direct reaction zone with magma (mineral intergrowths)	Forsterite + diopside + calcite + phlogopite
IV MAGSKARN	I GRANITIC	Dykelets which grade into mineral assemblages without contact metamorphism	Hedenbergite + diopside + mizzonite + quartz + plagioclase
	J PNEUMATOLYTIC-ASYMMETRICAL zoned dykelets		Quartz + microcline + calcite
	K HYDROTHERMAL	Irregular patches of late differentiates	Augite + wollastonite + plagioclase + mizzonite + hornblende
V RETROSKARN	L SERPENTINOUS	Retrograde alteration of forsterite clinohumite	Calcite + pyrite + chalcophyrite + mizzonite
	M TALCOSE	Retrograde alteration of dykelets and pre-existing isoskarms	Serpentine + ophicalcite
VI COMPLEX SKARN	ANY combination of types due to successive episodes of metamorphism and intrusion		Steatite

TABLE 11

characteristics. It is already in use by mining concerns and has been found to facilitate description, e.g. during the logging of borehole core for exploration and evaluation of ore reserves for quarries in the Marble Delta.

The main divisions of the classification have been named with reference to the principal processes responsible for skarn formation, viz. isochemical transformation (iso-skarn), metasomatism (metaskarn), contact metamorphism (con-skarn), magmatic activity (magskarn), retrograde metamorphism (retroskarn) or various combinations due to successive metamorphism and intrusion (complex skarn). Subordinate types have been distinguished as follows:

I ISOSKARN

A. Induced Type

This is an isoskarn formed from pre-existing granite or amphibolite dykes which have been disarranged or broken up during a later intrusive period and/or flowage of the marble, and in this process reacted with the calcite- or dolomite wall-rock. A new mineral assemblage is produced in this way through isochemical transformation. Examples of wholly transformed amphibolite occur in the Lot F O area, and some partly altered ones on Le Joncquet 165 Level and 130 Level in the Calcite Quarries. In the case of granite dykes the calc-silicate minerals form on the broken surface, leaving the original conskarn intact (Plate XIV, ph 2).

B. Nodular Type

In this case the calc-silicate clusters originated from the nodules which are considered to be a primary feature

of specific layers in the Le Joncquet Formation. This type of isoskarn becomes transitional on the W105 Level (site HH 170) where mizzonite forms the core of the clusters.

C. Banded Type

This was formed by transformation of impure calcareous beds which may also, through flowage of the marble, form discrete or boudin-like bodies of skarn minerals. The layering or banding is diagnostic and reflects the original bedding.

D. Transitional Isometaskarn (of sedimentary origin)

This type consists of both metaskarn and isoskarn material in appreciable proportions. Nests or cluster-like tremolite and diopside concentrations with a core of scapolite represent an example of this type.

II. METASKARN

E. Metasomatic emplacement of a mineral assemblage by fluids emanating from an intrusive gives rise to a metaskarn. The skarn shows no typical reaction zones with the enclosing marble wall-rock. Minerals which typify metaskarns are clinohumite in the Le Joncquet area and scapolite in the Lot F O area.

F. Transitional Metaconskarn is formed when appreciable material is metasomatically introduced into a contact metamorphic assemblage or when a metaskarn is partially modified by contact metamorphism during the same or a subsequent period of intrusion.

III. CONSKARN

G. Contact metamorphic or conskarn is formed in a narrow zone close to the intrusive contact where exchange of material took place over a short distance (including metasomatism within the contact zone). They are typical within a metre of an intrusive contact.

H. Reactional type

This is a conskarn which develops in direct contact with the magma. It is often characterized by several types of mineral intergrowths. Reactional skarns are very prominent in the field forming a partition between wall-rock and intrusive. In some instances they may be considered as part of a magskarn.

IV. MAGSKARN

I. A granitic magskarn is produced, for instance, by granitic fluids injected into calcite wall-rock which on subsequent flowage trapped the magmatic material. It consists of intimately intergrown quartz, microcline, calcite and diopside. These skarns are distinguished from boudins of granite, microcline dykelets or other veinlets in the Marble Delta by the fact that they have no regular contacts and show no reaction zone with the wall-rock. An example is present on site H 220, 130 Level.

J. Pneumatolytic-metamorphic veinlets with a skarn mineral assemblage are present on site P 251 next to and also within the amphibolite. The dykelets form reaction zones with both amphibolite and calcite wall-rock showing them to be of

magmatic/

magmatic origin, but their mineral composition is quite different from that of the granitic dykelets. Furthermore, the minerals crystallized in an asymmetrical arrangement with respect to dykelet contacts, comprising from the one side to the other: jadeite-diopside, scapolite plagioclase, wollastonite, diopside and hedenbergite. This zonal order changes along the dykelet and new mineral assemblages are formed. An explanation for the formation of this type of magskarn is that the alternating calcite and hornblende layers in the amphibolite caused a change from high to low X_{CO_2} by addition of H_2O to the system which becomes alternately closed and open during emplacement of the dykelet in a changing environment. The reaction selvage of green diopside and sphene proves its magmatic origin during the emplacement of the Buffalo Bill granite.

Another assemblage was formed in a vein-like skarn near the great dyke of Buffalo Bill granite in the central part of the Marble Delta (10M 1432). From wall to wall the mineral zones are serpentine-diopside-calcite- tremolite-diopside-serpentine.

K. Hydrothermal magskarn consisting of a hornblende-diopside-pyrite-chalcopyrite-mizzonite assemblage has been produced by the granite intrusion on the 130 and 165 Levels (I 219, O 230).

V. RETROSKARN

I. Serpentinous type

Serpentinization of forsterite in the marble was caused
by/

by the reintroduction of water into the rocks during the last phase of granite intrusion. Some of the forsterite bands are completely replaced by perfectly clear serpentine which due to its graphite and magnetite inclusions can easily be mistaken in the field for black amphibolite bands as shown in Plate XX, ph 2.

M. Talcoose type

Retrograde metamorphism of dykelets of unknown composition resulted in complete transformation into talc.

3. Examples

As an illustration of the situations encountered in the Marble Delta, two skarns will be discussed in more detail, namely (a) the incipient transformation of an amphibolite dykelet representing an example of exomorphic and endomorphic mineral assemblages produced by induced contact metamorphism, and (b) a typical conskarn with minor metasomatism close to an intrusive contact.

(a) At 165 Level Calcite Quarry, an amphibolite dykelet, 4 cm thick, has been broken up by flowage of the calcite marble and exhibits a conspicuously coarse recrystallization texture at the broken end of one block (Plate XXI). The unaltered part of the amphibolite consists almost wholly of brownish green hornblende with $2V_{\alpha}$ 76° - 90° and γ/c 22° - 32° . In the coarse part (isoskarn) of the dykelet the following minerals have crystallized: calcite, sphene, zoisite, clinozoisite, plagioclase, diopside, tremolite,

hornblende/



Dismembered part of amphibolite dykelet. Broken end shows coarse recrystallization and a zone of contact minerals against calcite wall-rock (Cc) representing an arrested metamorphic reaction (induced skarn).

Pm 1. Thin section of contact zone at broken end (1) with clinozoisite (Cz) and zoisite (Zo) penetrating wall-rock; note lamellar twinning on (100).

Pm 2. Thin section of contact zone at (2) showing cracked plagioclase (P) with clinozoisite, mizzonite (Mz), tremolite (T) and diopside (Di). Note the later rims of clear plagioclase around abovementioned minerals (crossed nicols, X70).

hornblende, pyrites and two unidentified fibrous minerals. The coarsely crystalline part is separated from the original amphibolite by a zone of radially arranged minerals as revealed by the pattern of calcite distribution.

White mizzonite crystallized on the contact of the amphibolite. It has a diffractometer peak separation of $4,312^\circ (2\theta_{400} - 2\theta_{112}^{\text{CoK}\alpha_1})$ and $0,55 (2\theta_{751} - 2\theta_{325}^{\text{CoK}\alpha_1})$. When this is compared with the mizzonite range (fig. 6) it corresponds to the 1 cm dykelet of blue scapolite (I 217). Towards the broken or free end of the amphibolite, scapolite gives way to plagioclase which incorporates inclusions of zoisite. White rounded grains of plagioclase occur in the calcite on either side of the dykelet. The $2V_\alpha$ varies from 73° to 81° , and according to Burri's curves the anorthite content ranges from 30 - 45 per cent. The plagioclase completely surrounded by calcite has the greatest An content. Cracked plagioclase grains analogous to those found in the thin granite dykelets are rimmed by clear plagioclase (Plate XXI, pm 2). Continuous zoning of the plagioclase confirms that this mineral assemblage is the product of an arrested metamorphic reaction apart from the other minerals appearing together in disequilibrium. Sphene crystallized on the outer fringe, and no doubt obtained its titanium by release from the crystal lattice of hornblende during recrystallization of the latter. White zoisite and clinozoisite aggregates are concentrated on the extremity of the contact skarn assemblage. In this section remnants of zoisite, and also secondary zoisite with anomalous blue

interference colours, occur amongst the semi-parallel, intergrown clinozoisite laths (Plate XXI, ph 1) and contain irregular domains of extinction. Optically the zoisite varies in $2V_{\gamma}$ from 44° to 56° . X-ray diffractograms of this specimen show that clinozoisite is present in much greater volume than zoisite.

The occurrence of both zoisite and clinozoisite in the same assemblage raises problems concerning the stability range of these two minerals. Pistorius (1961) pointed out that in applying the Clapeyron-Clausius law, one finds a very small difference in entropy between the two phases. He suggested that clinozoisite becomes a low-pressure phase in the case of starting materials containing iron as used in experimental work. Strens (1965) expressed doubts concerning the existence of a stable zoisite/clinozoisite assemblage even though it has been shown by Rogers (1924), Foye (1926) and many others to occur in nature. Calculations done by Kepezhinskas (1967) on the discriminate function Dx , which show an overlap in composition, led him to conclude that a polymorphous relationship exists between zoisite and clinozoisite.

The mineral assemblage described from the amphibolite reaction zone probably never reached a state of complete equilibrium because of the waning effects of the granite intrusive, which, together with the dissipation of heat, affected the P_{H_2O, CO_2} conditions. The initially high P_{CO_2} and volatiles from the granite favoured the early precipitation of mizzonite. Recrystallization of the amphibolite

started on the broken side of the dislocations. Release of H_2O and Na from the hornblende led to the formation of epidote group minerals, followed by plagioclase. Calcite crystallized as a last phase within the coarse-grained recrystallized part.

The mineral assemblage of this isoskarn is clearly in a state of disequilibrium and has the appearance of retrograde metamorphic products, but this is due to the conditions present in the semi-closed system with internal addition of H_2O supplied during the recrystallization of hornblende. This isoskarn which was formed by induced metamorphism on a pre-existing amphibolite dyke demonstrates the exceptionally short distances through which Al migrates (Carmichael, 1969). The very existence of isoskarns which preserve bedding traces of the original sediments, is based on the relative immobility of Al during metamorphism. This is particularly well exhibited where a bedding trace is reflected by a line of sparse euhedral crystals of pink spinel. A similar low mobility of Al is shown by the next example.

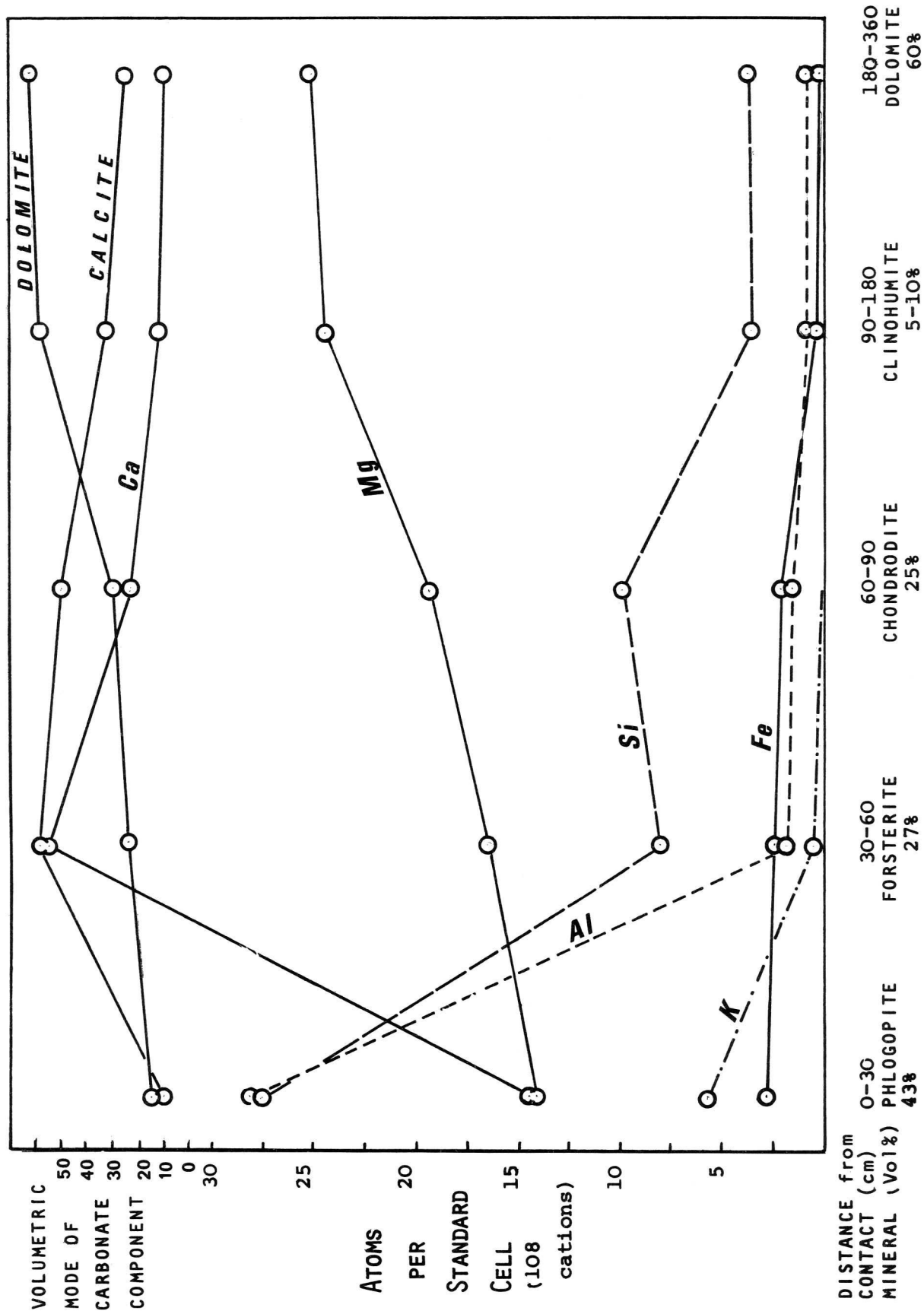
(b) The conskarn on Lot F 0 is associated with coarse microcline microperthite granite similar in character to the Buffalo Bill granite dykes. The conskarn shows a progressive variation from a 21 cm wide phlogopite zone against the granite through a dark green zone of forsterite followed by pale green chondrodite and clinohumite grading into dolomite marble. This type of conskarn with somewhat modified mineral assemblages is widespread throughout the dolomite marble in association with granite contacts. Five specimens were

collected/

collected for partial chemical and modal analyses. In order to establish the geochemical variation from the phlogopite outwards into the dolomite marble, the skarn units must be compared isovolumetrically. Accordingly, the ions per standard cell of 160 oxygen ions were calculated (Barth, 1959) and the results presented in fig. 7. Ca and Mg are found to vary antipathetically with Si, Al, K. The drop in magnesium is mainly due to the decarbonatisation of the dolomite, while calcite is being produced by metamorphic reactions leading to the formation of clinohumite, chondrodite and forsterite. Magnesium was removed from the marble, which in part led to the formation of phlogopite, and silica was introduced into the marble but reaches the normal level of the marble within 3 - 6 feet of the contact zone. The Fe, K, Al show an abrupt change in trend within 30 cm from the phlogopite. The change is even more abrupt in the calcite marble where only the reactional type of magskarn is present.

A similar type of skarn from the old dolomite quarry was described by Hatch and Rastall (1910) but regarded by them as a subsequent reaction rim on boulders of granite which were supposed to have been deposited with the limestone.

FIGURE 7. ISOVOLUMETRIC COMPARISON OF IONS PER UNIT SKARN



VI. CARBONATE REPLACEMENT BODIES AND VEINS

Under this heading several large bodies of dolomite and calcite are described which do not properly belong to the stratigraphic succession, although previous workers regarded them as part and parcel of the marbles. Du Toit (1918, 1946) included the reddish variety within his "Upper Marble" unit. They exhibit considerable textural variation, are predominantly of dolomitic composition with associated calcite veins, and are considered to be of late (secondary) replacement origin.

(1) Ferruginous dolomite

This occurs as lenticular bodies mainly along the western periphery of the Marble Delta. Extensive outcrops are found on Lot F N, The Forest, Simuma, Le Joncquet and to the north-west along the Umzimkulu River valley. The bodies range from a few metres to several hundred metres in length and attain their best development in calcite marble on Le Joncquet. They usually thin out where they cut across dolomite marble. Replacement features are displayed by re-entrants into calcite wall-rock, where the ferruginous dolomite appears to have sought out relic bedding planes and minor structures. The irregular contacts and surface outlines of these bodies against calcite marble often resemble filled-in solution cavities. Also on a larger scale their shape is mostly controlled by pre-existing primary and secondary structures. For example on Le Joncquet (Maps 1 and 2) the dolomite bodies are arranged in a sub-

parallel/

parallel manner diagonally across the strike of the calcite marble. This pattern roughly parallels the main deformation zone which is equated with major thrusting along the Umzimkulwana Valley.

It is clear that the replacement bodies were introduced after the period of metamorphism but before the peneplanation of the pre-Cape landsurface. No direct age relationship could be established with the last granite intrusions. However, the granites must be older because they suffered deformation and are secondarily altered along the same zone that is characterized by dolomite replacement. Furthermore no large scale migration of magnesium was associated with the intrusion of the granites. A Karoo dolerite dyke cuts across reddish ferruginous dolomite and white calcite veins on Le Joncquet.

The dolomite bodies are easily distinguished from the other carbonate rocks by their colour which depends on the percentage iron, and also by occasional elephant-skin weathering which is never seen on exposures of dolomite marble. The reddish-brown colour is due to minute specks of iron oxides which probably originated by exsolution from the dolomite lattice. No ankerite has been encountered so far. Two specimens collected in the Rayon Quarry were analysed and found to contain 4,3% and 4,6% Fe_2O_3 (Table 12). Towards the south on Lot F N the colour becomes grey white and pinkish to chocolate brown and the grain size shows exceptional variation from a sugary (1 mm) type to a mosaic texture with grains up to 3 cm in diameter. These variations

mark at least three consecutive phases of replacement. The pinkish dolomite was followed by coarse reddish to brown dolomite containing brecciated inclusions of the earlier phase. Fragments of both types are enclosed by a third phase consisting of whitish calcite and dolomite.

Table 12: Chemical Analyses of Replacement Dolomite

	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MgO	CaO	Na ₂ O	K ₂ O	L.I.	Total
(a)	0,5	1,2	4,3	18,6	30,5	0,07	0,08	44,8	100,05
(b)	4,4	1,9	4,6	14,3	33,6	0,05	0,06	41,1	100,01

(a) reddish brown dolomite site Z 255

(b) chocolate brown dolomite site Z 250

The $\delta^{13}\text{C}$ values listed in Table 13 and reproduced by permission of Dr. M. Schidlowski, show that the exceptionally coarse marble which suffered successive periods of metamorphism has essentially the same bulk $\delta^{13}\text{C}$ isotope geochemistry as sedimentary carbonates. The coarse replacement dolomite shows a similar result and must have originated from sedimentary carbonate, probably of the same stratigraphic sequence.

Table 13: $\delta^{13}\text{C}$ values of Marble and Replacement Dolomite

<u>Locality</u>	<u>Description</u>	<u>%</u>	<u>%</u>	$\delta^{13}\text{C}$
		<u>CO_3</u>	<u>Dolomite</u>	(‰, PDB)
(a) HH 169	Coarse white dolomite marble	96,5	86,5	+0,4
(b) H 220	Coarse white dolomite marble	96,0	< 1,0	+2,3
(c) H 219	Greenish yellow calcite marble	98,0	< 1,0	+1,8
(d) H 218	Coarse blue calcite marble	97,0	< 1,0	+1,3
(e) O 240	Pale blue calcite marble	94,5	< 1,0	+1,8
(f) 7F 4132	Dark grey calcite marble	98,0	< 1,0	+0,8
(g) 6R 3233	Dark brown replacement dolomite	96,5	96,5	-0,3

(Analyses by Max Planck-Institut für Chemie, Mainz, Germany)

(2) Late calcite

In addition to large (30 cm) clusters of transparent calcite in the dolomite bodies described above, pure white calcite was precipitated much later in the form of veins along minor faults and fractures. They are usually located in the vicinity of the replacement bodies. Some of them contain a core of milky white quartz a few cm wide.

At the Rayon Quarry numerous sub-parallel calcite veins up to 20 cm thick are found along a zone of deformation. They cut each other and were thus emplaced in stages. A set which fans out from a horizontal to a vertical attitude is associated with localised displacement fractures. The calcite veins are clearly later than ferruginous stained cracks in the calcite marble but a later series of ferruginous cracks traverse the calcite veins as well. Karoo dolerite is younger than the calcite veins.

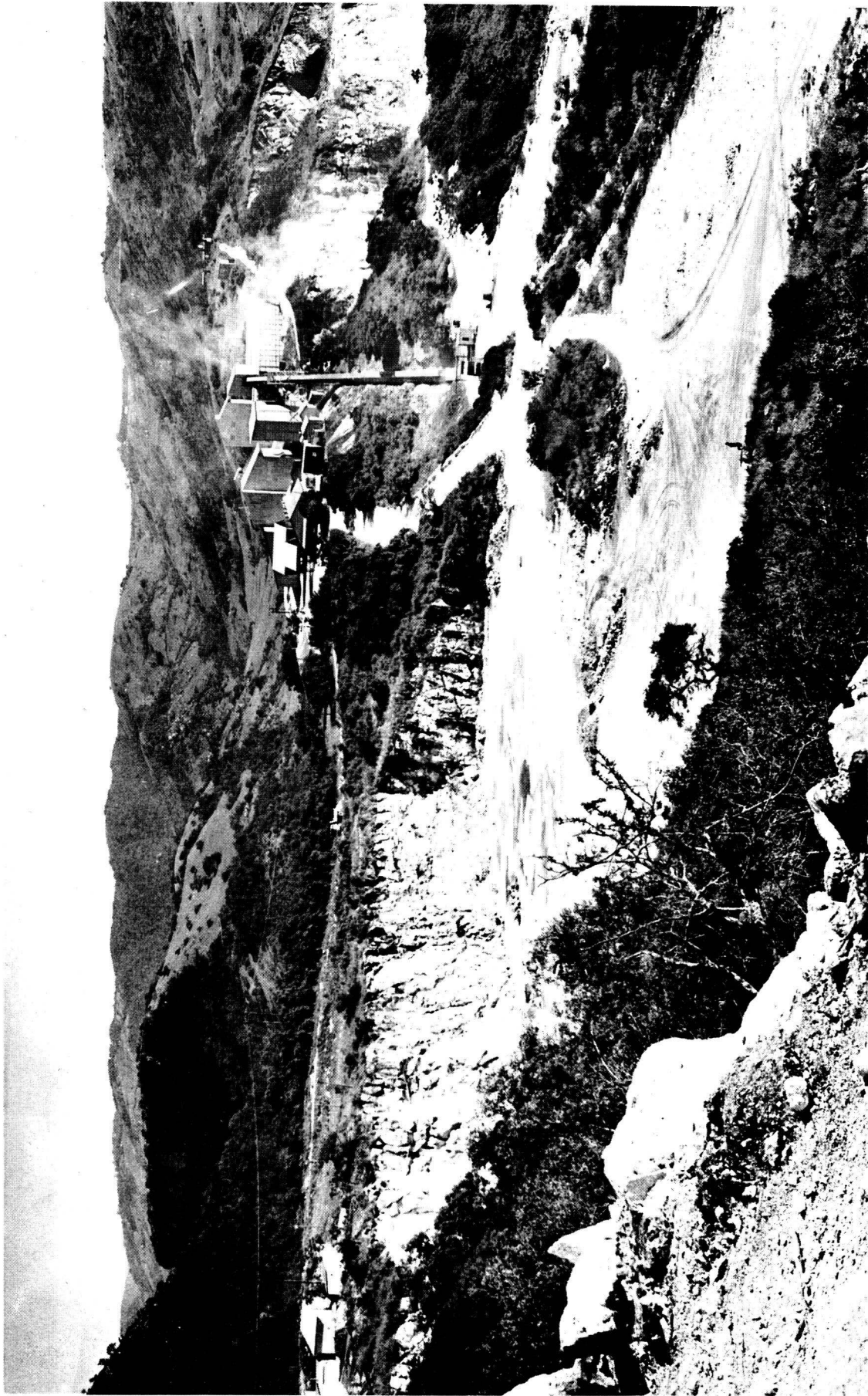
VII SUPRACRUSTAL FORMATIONS

1. Table Mountain Sandstone

West of the Marble Delta the high cliffs of Table Mountain Sandstone add to the majestic grandeur of the 400 metre gorges of the Umzimkulwana and Umzimkulu Rivers. The almost horizontal sandstone beds build the Oribi flats and the Murchison plateau further westwards. The sandstone ends abruptly against the Renken fault system (Plate XXII) which encloses subsided blocks of Table Mountain Sandstone. The layers dip 2° east on Ocean View and Oribi Flats but may be tilted up to 20° along faults branching off and parallel to the Renken fault.

The sandstone varies in tint from light brown to white and is silicified in places. Occasional pebbly layers are encountered up to a few cm thick (pebbles 1 cm in diameter). The lower part and the base of the formation is an exceedingly fine-grained sandstone which contrasts with the coarse felspar grit and micaceous sandstone in the southern Durban area (Chatsworth). Du Toit (1946) described a reddish felspathic sandstone at the base near Bendigo and also towards Margate. The orthoquartzite marker of the Durban area is not distinctly developed but this may be due to the possibility that the Basal zone of Rhodes and Leith (1957) is not represented in the Marble Delta area.

The fine-grained nature of the sandstone is remarkable as the whole succession peters out northwards within about two kilometres. (Plate XXII). This is due to a distinct



Northward view with the Rayon Quarry in the foreground and the Umzimkulu Lime Company's offices and plant on the site of the old Lot 21 Quarry with the Calcite Quarry below. Towards the left an outlier of Table Mountain Sandstone is present on the farm Buffalo Bill. Further left on the horizon Dwyka Tillite lies directly on Basement granites. The valley behind the buildings marks the Renken fault. The St.Faith's granite builds the hills in the upper right corner. (Jan.1973)

change in the sedimentary basin which becomes a clean-swept zone of deposition on granite terrain. The unevenness of the floor on the marble is evidenced by filled-in cavities and maroon sandstone dykes. The cavity fillings consist of reddish conglomerate and clastic felspar. This material seems to indicate that the area was at times above the base level of erosion while major deposition was taking place further north. The conglomerate, clastic felspar and maroon sand in the marble may represent the same facies of deposition as the Basal Zone of Durban. If so, then the sandstone may be the equivalent of the Orthoquartzite Marker mapped by the writer during 1964, in the Durban area.

Crossbedding on Ocean View is of the 180° fan type and can only be recognised as such on a horizontal plane. Any measurements based on vertical exposures only may lead to an error of at least 50°. Furthermore, different genetic types of crossbedding should be measured separately. The main direction of transport indicated by abovementioned type is found to be from the north.

2. Dwyka Tillite

In the western part of the Marble Delta, below the access road to Le Joncquet, an outcrop of tillite overlies Table Mountain Sandstone and abuts against the marble. It is part of a fault block that was tilted at least 40° in a graben between two branches of the Renken fault system. Undisturbed tillite occurs on Oribi Flats Lot 5 (not shown on Du Toits map of 1946), indicating that the tillite has

dropped down about 500 metres.

3. Karoo Dolerite

A large number of dolerites, not shown on previous geological maps, are found in the marble and associated granites in the form of sheets and irregular dyke-like bodies. They are usually decomposed and may be recognised in the field by their brown crumbly soil which differs from amphibolite soil in colour and absence of hornblende chips. The two largest sheet-like intrusions which attain a thickness of up to 100 metres are present in the eastern and central part of the Marble Delta. The irregular form of the dolerite exposed on The Glen, similar to that of the granite intrusions, is probably due to stoping as no evidence of flowage of marble on the contacts was observed in the quarries. Dilation and stoping were the principal methods of emplacement whilst attrition of calcite and dolomite grains on the contact produced a smooth surface.

The body on Lot F 0 extends to Le Joncquet hill (Map 1, 8 M) and dips eastward. The dolerite along the Umzimkulu River on the West Slopes bank is considered to be the same intrusion. It crops out intermittently along the hillsides of Westlands towards the north-west where at Buffalo Bill it lies at a much higher topographic level, as on Le Joncquet. On Lot F 0 the dolerite is coarse with an ophitic texture.

Vertical dykes one foot thick are present in the Calcite and Rayon Quarries. They contain insets of clinopyroxene in a chilled groundmass. A peculiar clastic deposit attached to the dolerite dyke shown on Plate XV was

noticed on the 165 Level. It is characterized by "flow lines" and crossbedding as well as megascopic graded bedding. In places it is so fine that the rock resembles a varved shale. The layering becomes horizontal and coarser with larger fragments of quartz and calcite towards the northern side. The dolerite itself contains rounded pieces of quartz and calcite. The explanation seems to be that the dolerite magma intersected an opening in the marble which led to a larger cavity and this was filled up in an explosive manner leading to brecciation in places and laminar flow elsewhere. Since the inferred direction of flow in the clastic body is from south to north, the dolerite dyke probably emanated from the large intrusion to the south on Simuma Hill.

On Lot F N dolerites intruded the irregular pre-Cape faults and crushed zones in the granite; they cut across calcite veins and dolomite replacement bodies.

VIII STRUCTURAL GEOLOGY

1. Regional Fold Structure

The Marble Delta was described by Du Toit (1920) as "a twisted mass." This may be true as a general statement but it epitomizes the extremely complicated structure of the marble and associated rocks only very inadequately. Even detailed geological mapping and measurement of all possible foliations and lineations did not enable the writer to unravel the structure as well as would perhaps be possible in a better exposed area.

At first sight it appears from the geological map that the metasediments are in the form of a dome-like structure with the younger beds dipping peripherally outwards into the surrounding granites. However, when quarry faces were opened up it was found that what appeared to be normal bedding, was flattened-out recumbent tongue-shaped folds containing partially wiped-out structures indicative of an earlier tectonic history. This conclusion was corroborated by the lineation and contorted folding in haphazardly disarranged blocks of metaquartzite and especially by the discovery of a deformed conglomeratic facies of the metaquartzite below East Slopes Quarry (Plate XXIII; cf. chapter III). Twenty-three flattened pebbles were measured on two surfaces at right angles to the foliation plane and were found to have an average elongation ratio of 1 : 7,4 . On the basis of this exposure the drag folds and contorted banding of the quartzite on the opposite bank of the Umzimkulu River were

found/



Photographs of metaquartzite on East Slopes (Map 1, 14P) showing quartz lenticles which have been interpreted as pebbles in a deformed conglomeratic facies. This is brought out by selective weathering and is not visible on a broken surface. Ph 1 shows a vertical face with an assortment of clasts varying in size and shape. Ph 2 shows a more regular type with well-defined convex shape.

found to be traces of the deformed conglomerate. On close observation a single pebble can be followed out in a Z-shaped fold.

These structures reveal a period of intense deformation (designated as F_1) which is undoubtedly earlier than the folding (F_2) responsible for the mappable distribution of stratigraphic units. The F_1 deformation is held to be related to the main regional metamorphism. Subsequent differential flowage of the marble and dislocation of metaquartzite have obliterated the F_1 structures to such an extent that it is believed well-nigh impossible to reconstruct their fold axes; an exception is noted below under F_2 folding.

Relict s-surfaces are preserved in the metaquartzites, often in the form of calcareous intercalations now represented by diopside, while related structures are obliterated in the adjoining marble. The fixation of Ca and Mg in the inosilicate framework, together with the loss of CO_2 from the system must have had an effect on the ductility response of such intercalations under compressive stress. They acquired a rigidity approaching that of quartzite in contrast with the adjoining marble in which flowage took place. This is but one example of the manner in which development of new mineral assemblages affects the deformation of a metamorphic rock; the changes in ductility are bound to be progressive. The metaquartzite, being resistant to weathering, also forms the most conspicuous outcrops. Their lineation and dip reveal nothing of the overall structure and it is a pity

therefore/

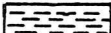
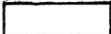


therefore, that these marker beds were broken up as variously orientated blocks during the F_2 and subsequent F_3 deformations.

Any attempt to draw cross-sections across the Marble Delta based on strike and dip of metaquartzite or flow folded marble will have little or no relationship to the true structure unless the successive periods of deformation are recognised. Previous efforts to utilise local attitude of beds for this purpose have led to misleading reconstructions (Draper, 1895; Du Toit, 1946; Simpson and Tregidga, 1956). The only useful purpose of a recognizable s-surface in the Marble Delta is that it may enable a distinction between structures of different ages and their relationships towards different granites to be made (cf. Petrofabrics).

The F_2 or main fold axes can be deduced from the geological map. The foliation of The Wolds and St. Faith's granites is sub-parallel to the F_2 fold trends in their vicinity. Fig. 8 is a sketch map showing the F_2 structural features and generalised outlines of the three formations belonging to the Marble Delta Group, with the omission of the younger granite intrusives (Westlands, Oribi Gorge and Buffalo Bill) and the effects of subsequent faulting. The main quartzite is idealised as a continuous marker horizon. The central structure is seen to be a skew dome which closes north-west of Le Joncquet and fingers out in the opposite direction to form a series of curved plunging anticlines and synclines. The curvature is not due to superimposed folding but to simultaneous flow deformation during the F_2 period.



FIGURE 8. STRUCTURAL SKETCH MAP SHOWING RECONSTRUCTION OF THE MAIN FOLD TREND (F_2)

- | | |
|---|---|
|  | CHERRYWILLINGHAM FORMATION |
|  | ORIBI FORMATION |
|  | LE JONQUET FORMATION
(with quartzite marker) |
|  | THE WOLDS GRANITE |

The Dolomite Quarry is situated near the centre of the dome where the dip of the marble is flat to horizontal; elements of F_1 folding are probably present here as evidenced by minor anticlines in relatively intact quartzite layers, their axial plunge being to the north-west whilst the main lineation pattern of this area plunges southwestwards.

Fig. 9 is a perspective drawing in which F_2 lineation directions have been projected on an arbitrary plane (approximating the contact between the Oribi and Le Joncquet Formations) in an attempt to portray the overall F_2 structures in three-dimensional form. Lineations were mostly measured in amphibolite and along linear bundles of wollastonite in calcite marble. It will be seen that the lineations converge towards a tight, steeply plunging antiform on Westlands and this appears to be a focal point in the deformation of the Marble Delta. The tight antiform opens out into the major dome already described. This is followed southwestwards by either (a) a concealed synform or (b) an eroded antiform, subsequently modified by faulting along the present Umzimkulwana River. Where the Le Joncquet Formation reappears on Lot F N it forms a recumbent fold plunging south and south-west subparallel to lineations on the southwestern flank of the major dome. The marble outlier on Lynwood, extending to Daddy's Quarry beyond the southern boundary of the map represents another deeply infolded antiform, probably thrown up by subsequent faulting. A subsidiary elongated dome-like structure is inferred to be present in the Oribi Formation north of Le Joncquet.

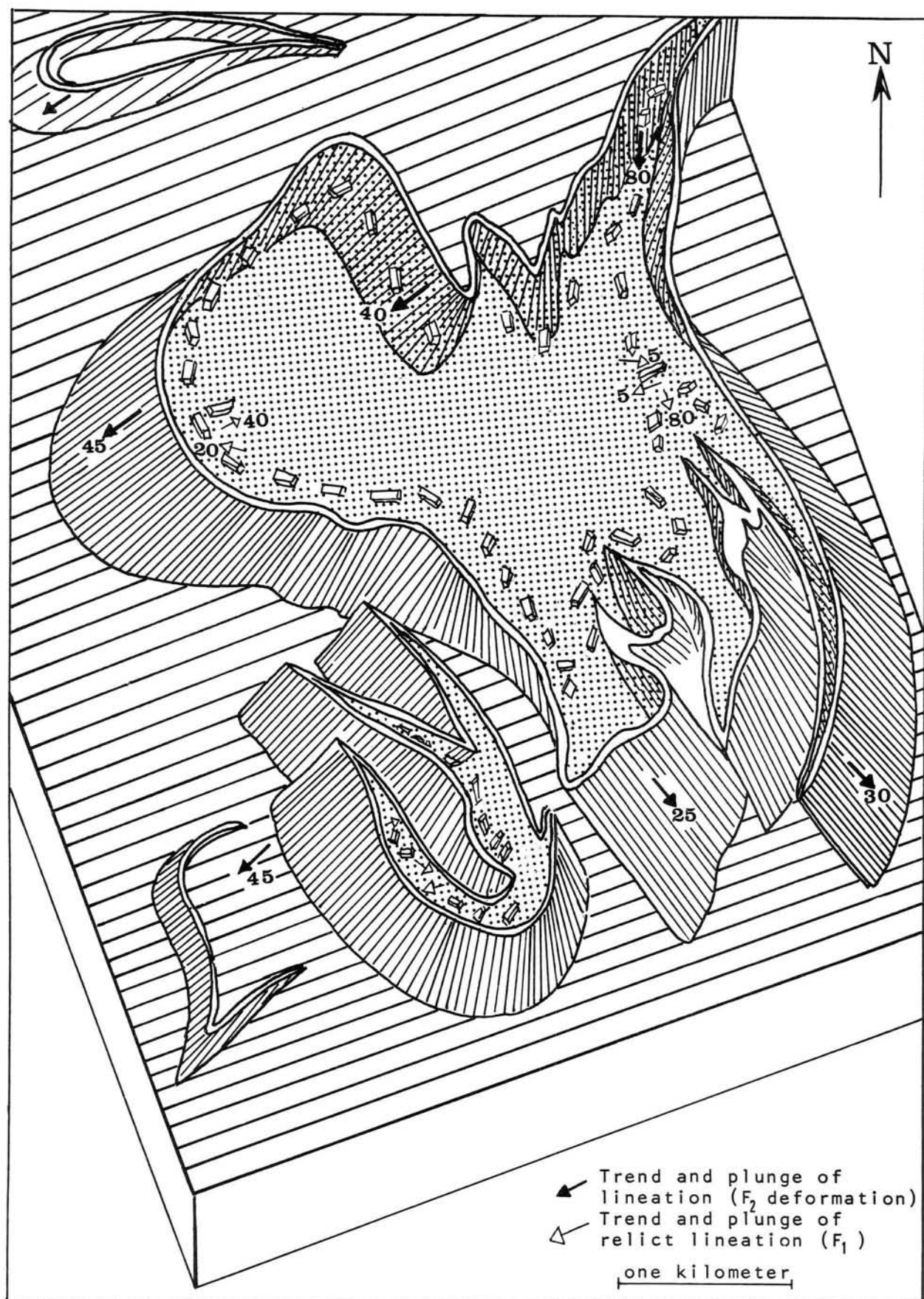


FIGURE 9. Perspective drawing showing the trend and plunge of lineation. Lineation is projected on an arbitrary plane (which does not necessarily reflect the fold pattern). Main metaquartzite shown as disorientated blocks.

The Marble Delta Group not only suffered at least two periods of regional folding and associated metamorphism, but was heated up and deformed again during the intrusion of the granites (the F_3 deformation). These last tectonic effects were locally intense but regionally widespread due to the profusion of intrusives, and again destroyed most of the pre-existing minor structures.

2. Structures related to Intrusions of Granite

The conditions under which the granite dykes were emplaced led to the formation of sausage-like shapes strongly reminiscent of typical "boudinage" structure developed in regionally metamorphosed terrains. The boudins or oval granite bodies are separated by hourglass-shaped pillars of calcite. In this type of discontinuity the dyke portions have smooth, rounded, often overlapping ends, showing that the intrusion was not only initiated through dilation but was assisted by a tunnelling effect which came into play where the dilation fracture was resealed or never quite open as a result of recrystallization. In this way blunt tongue-like instead of dyke-like intrusions of granite would develop in wall-rock undergoing plastic flow in response to the overall heat supply by numerous related intrusions. With such an increase in the ductility of the marble parallelism of the walls is seldom attained.

Granite dykes in marble often appear to be folded. The "folding" has features analogous to ordinary folds in beds of different competency except that in this case a granitic fluid was initially present in a more viscous

matrix of marble, but gradually solidified while a constant relationship would hold if the rocks were solid from the beginning. The amplitude of the "folds" in any specific area is related to the thickness of the dyke or sheet and to the ductility factor of the marble which, in turn, is determined by the heat supplied to the wall-rock. This is illustrated by an instance where a granite dyke is straight within amphibolite but becomes contorted where it enters the marble (fig. 10). On the 165 Level of the Calcite Quarry (site 0 235) there are two contorted granite bodies, one with a thickness of about 7 m and an amplitude of 28 m and another one 20 cm, both showing a similar wavelength/thickness ratio of 4. In a matrix of dolomite marble which is less reactive on recrystallization and therefore more viscous, the thickness and amplitude of a contorted dykelet diminishes rapidly away from the parent intrusion. The wave pattern is more regular and clearly developed in the calcite marble. These observations lead to the conclusion that the stress field changes rapidly from one locality to another and also continuously at one locality depending on the rate of injection and heat supply. The folds are not controlled by principal stressfields and therefore, unless this is taken into consideration, any petrofabric interpretation of the wall-rock would be in error.

Figure 10 shows a thin granite dykelet in which the sinuosity has become disharmonic. This is commonly called *ptygmatic* folding and has taken place, in this case, before the magma consolidated but after the marble was rendered

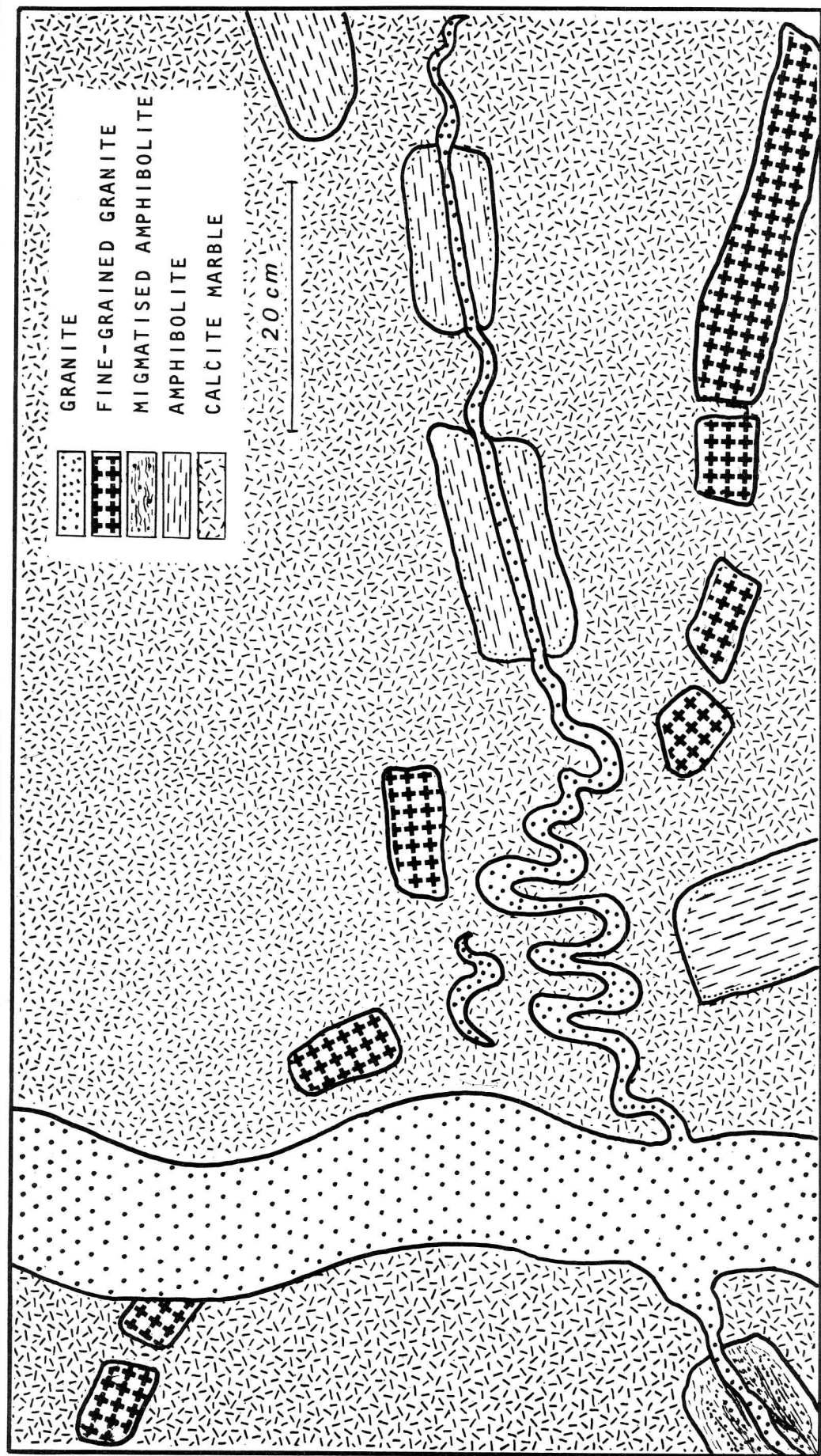


FIGURE 10. Schematic drawing showing ptygmatic folding of granite dykelet (Map 2, 165 level) in calcite marble contrasting with its straight configuration when traversing dismembered amphibolite. These phenomena are attributed to relative ductility of the marble caused by the emplacement of the granite. The fact that a pre-existing granite dyke was dismembered but not folded proves that the migmatitic structure originated before final consolidation of the dykelet. Note the migmatization of amphibolite in lower left corner and apparently isolated portion of ptygmatic dykelet next to the feeder dyke

mobile. Mehnert (1968) has given a detailed discussion of the many genetic interpretations by different authors on the development of ptygmatic folds, and concluded that two groups can be distinguished in principle, namely ptygmatic folding of primary and of secondary origin. A secondary origin is usually favoured, the folds being ascribed to a difference in competence between matrix and layer, or to remobilization in gneissic rocks, or to the behaviour of a minimum melt. In the marble all interpretations are ruled out except injection of granite. This is in accordance with the view adopted by Niggli (1954) and Wilson (1952), except that the absence of protoclastic effects shows that there is no need to postulate forceful injection, which was commonly considered in the literature to be the unworkable part of their hypothesis. A similar interpretation may be given to ptygmatic folding at Slipper's Bay (McIver, 1957; Plate I, ph 5) where the Malmesbury sediments were softened up by intruding granite.

3. Petrofabrics

Experimental studies of calcite deformation and recrystallization have been carried out by many authors (Turner, 1949; Griggs et al, 1953; McIntyre and Turner, 1953; Turner et al, 1954; Turner, Griggs, Clark and Dixon, 1956; Griggs, Paterson, Turner and Heard, 1960; Heard, 1963) and similarly the preferred orientation of dolomite was studied by Fairbairn (1941), Handin and Fairbairn (1955) and Christie (1958). A review of their work, of experimental studies on the

recrystallization/

recrystallization of dolomite, and a comparison of the preferred orientation of calcite and dolomite in deformed rocks are given by Neumann (1969). All these investigations are consistent with earlier observations (Ferreira and Turner, 1964) and confirm that there is a strong preferential alignment of the c-axes with the axis of maximum principal compressive stress.

The general assumption underlying the study of mineral fabric showing directive growth in marble is that it is indicative of the principal stress direction. To test the validity in the Marble Delta of this assumption a few orientated specimens of dolomite marble with interstitial calcite were collected from a structurally known and mapped area with good exposures. The site selected (II 163) was in an area where a few minor synclines and anticlines (about 10 metres wide) plunge 25° to the north-west. Parallel and close to these folds a metaquartzite layer is present in the nose of a fold, relatively undisturbed by later folding which indicates that this area suffered less deformation than elsewhere (as for instance on the western part of Le Joncquet where lineation plunges 45° to the south-west).

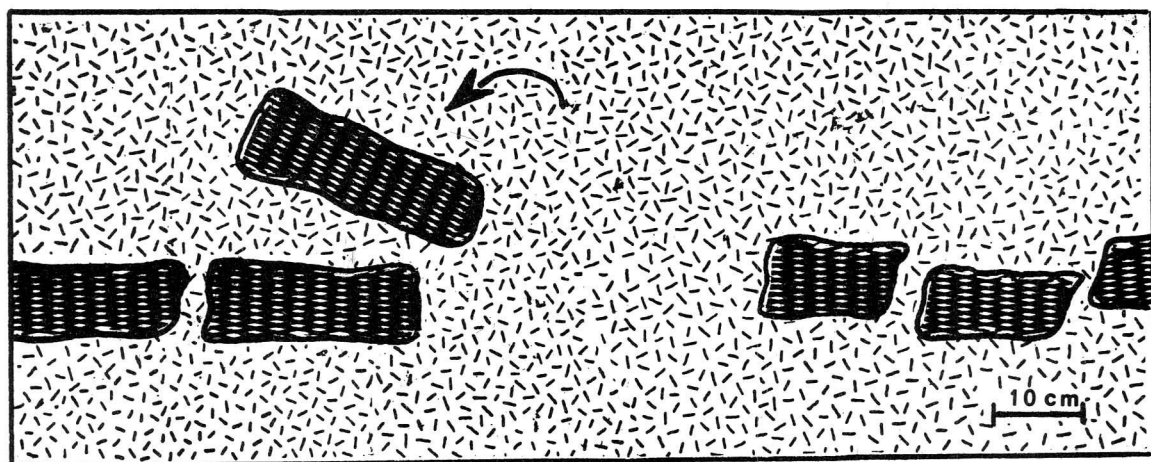
The c-axes of calcite and dolomite were measured on the Fedorov stage and plotted on an equal area net. The thin sections were alizarin-stained which also showed up the boundaries of the recrystallized parts within the parent calcite. In almost every thin section the c-axes of calcite and dolomite have roughly the same distribution on the

equal area net. The c-axis girdle was found to be normal to the NW - SE striking axial plane of the anticline. This type of b-direction orientation must be attributed to crystal alignment during plastic flowage after initiation of the fold structure.

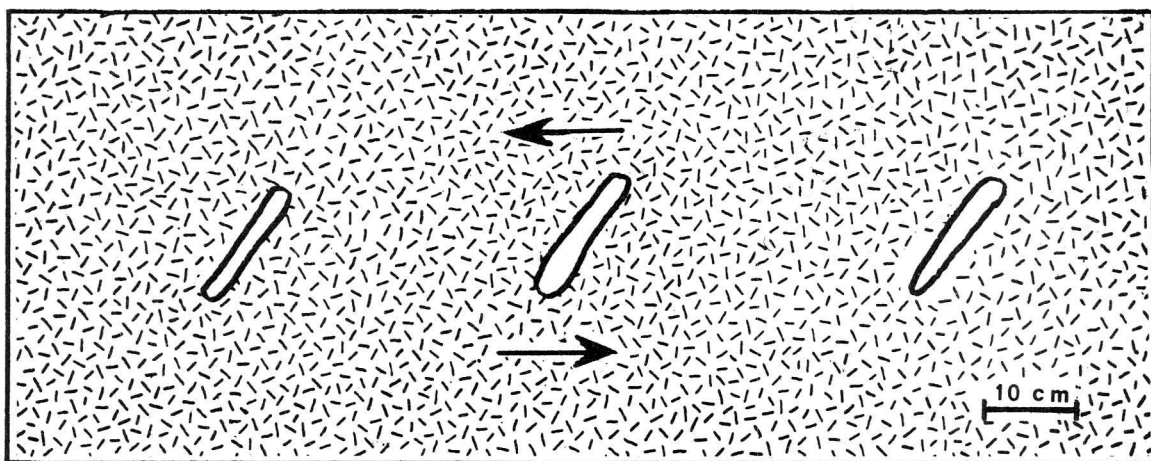
Dieterich and Carter (1969) in their studies of stresses in a viscous fold, concluded that fabric data record cumulative intergranular flow during the course of the process of folding. However, the above results which also demonstrate a scattering of the c-axes are incompatible with such an explanation. They are due to superimposed metamorphism during which the interstitial calcite was the first to recrystallize leaving the host crystal and dolomite intact (Plate III, pm 2). Embayed calcite grains in a dolomite host are indicative of an earlier period of crystallization and thus quite different from the parts which recrystallized at the expense of the parent calcite. The c-axes of recrystallized domains in the parent calcite show a progressive shift in orientation (along a great circle plot) showing a linear displacement of the localized principal stress field for a single metamorphic period. The larger insets of calcite (Plate II, phs A and B) showing parallel lamellar growth with dolomite fall within the same girdle of c-axes indicating a simultaneous growth of calcite without incorporating magnesium into the lattice.

That the alignment of c-axes in calcite marble caused by recrystallization under the influence of various kinds of movement resulting in different orientation patterns, is

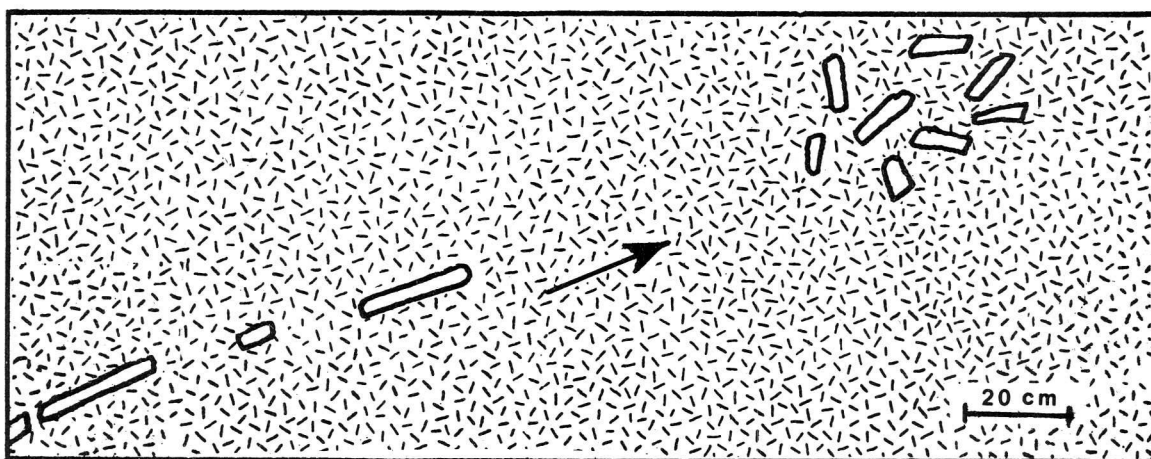
illustrated/



A



B



C

Fig. 11. Sketch maps showing three different types of differential flowage in calcite marble that will affect the orientation of c-axes.

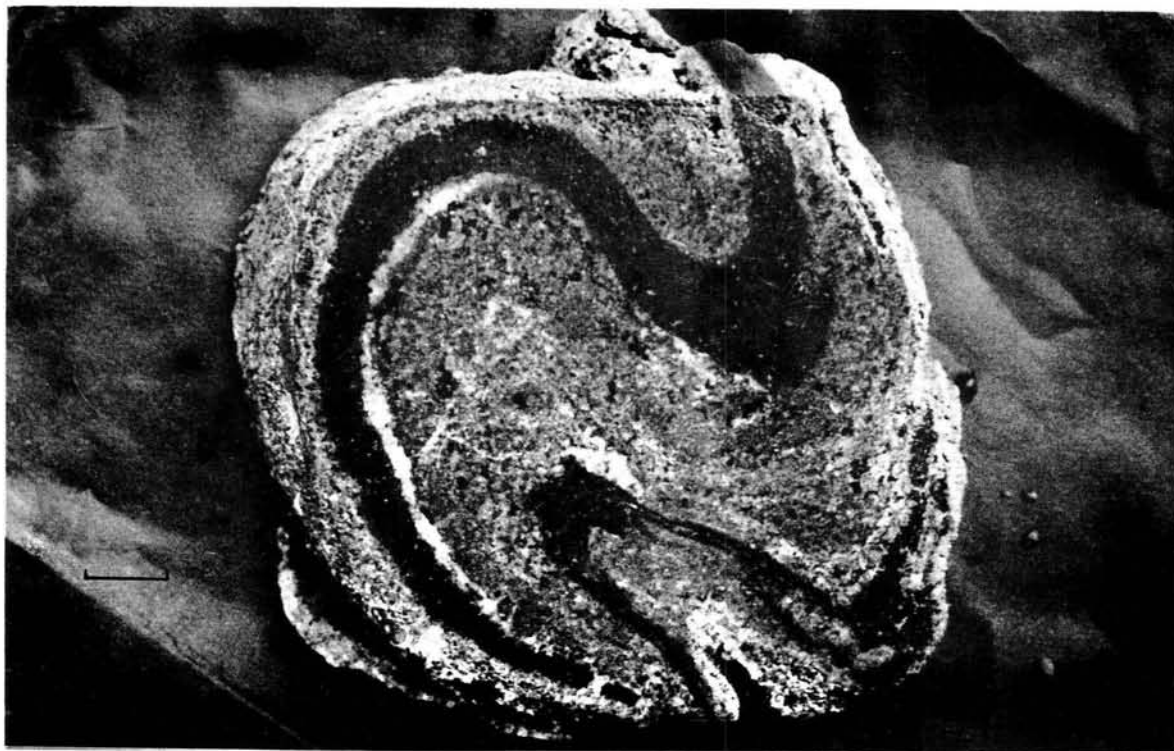
- A. Overturned block of dismembered granite dykelet (site R 245)
- B. Detached and rotated portions of calc-silicate bed (site 3P 2231)
- C. Calc-silicate blocks grouped together by flowage parallel to bedding (site P 221)

illustrated by figure 11.

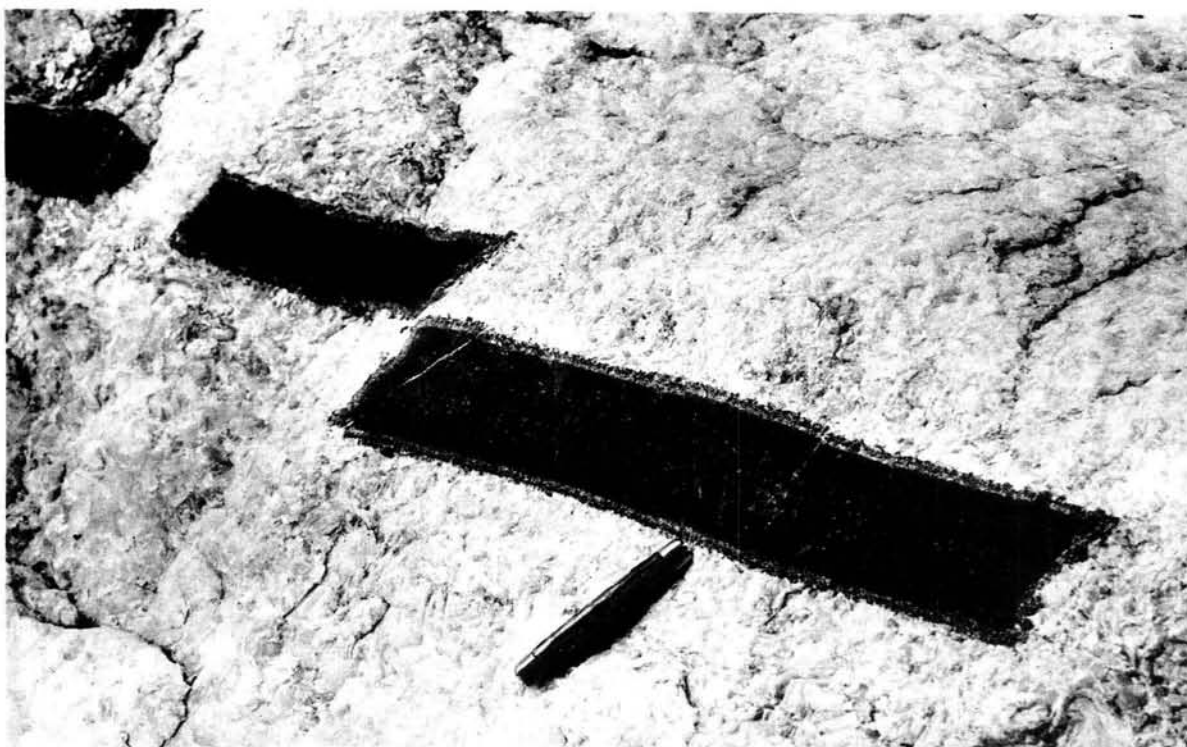
It is clear that the principal compressive stress field of any particular area cannot be determined by petrofabric analysis of the marble without a knowledge of the past tectonic history and present structure and mineralogy, including a distinction between different mineral assemblages. In the Marble Delta there is ample scope for preferred orientation studies of carbonates pertaining to relic S-surfaces and later flowage. Other minerals for example clinohumite, were found to possess excellent preferred orientation which may be used to date the metamorphic events which produced particular mineral assemblages. Similarly, in the amphibolite on Lot F 0 (site 11 V) preferred orientation is present in hypersthene and hornblende making it possible to reconstruct an older stress pattern which existed prior to the period of granite intrusion and flowage of marble. In the same area around the old Dolomite Quarry the orientation of c-axes of interstitial calcite can even be roughly determined in the field on outcrops of coarse dolomite marble from macroscopic parallel growths on (0001). In these outcrops the c-axes were seen to lie within the plane of relic bedding. In calcite marble, however, the scattering of the c-axes is not expected to be parallel to the bedding due to differential flowage which is much more marked than in dolomite as shown by the block movement of dismembered sills and dykes (fig. 11, A B, Plate XXIV, ph 2).

In conclusion it may be emphasized again that in an area like the Marble Delta, petrofabrics is useful only

when/



Ph 1. Section through a single rod of layered amphibolite consisting of a compressed fold, dislodged by weathering. These rods are remarkably straight and up to a few metres in length. They are due to F_2 folding superimposed on F_1 .



Ph 2. Disarranged blocks of an amphibolite dykelet (8 cm thick) in calcite marble, each with a continuous rim of induced skarn. White streaks of scapolite line pre- F_3 fractures. The ductility contrast resulted in contrasting petrofabrics of the two rock types (compare ph 1 and fig. 11).

when the major structural data are already known.

4. The Glen and Renken Fault Systems

The Glen Fault

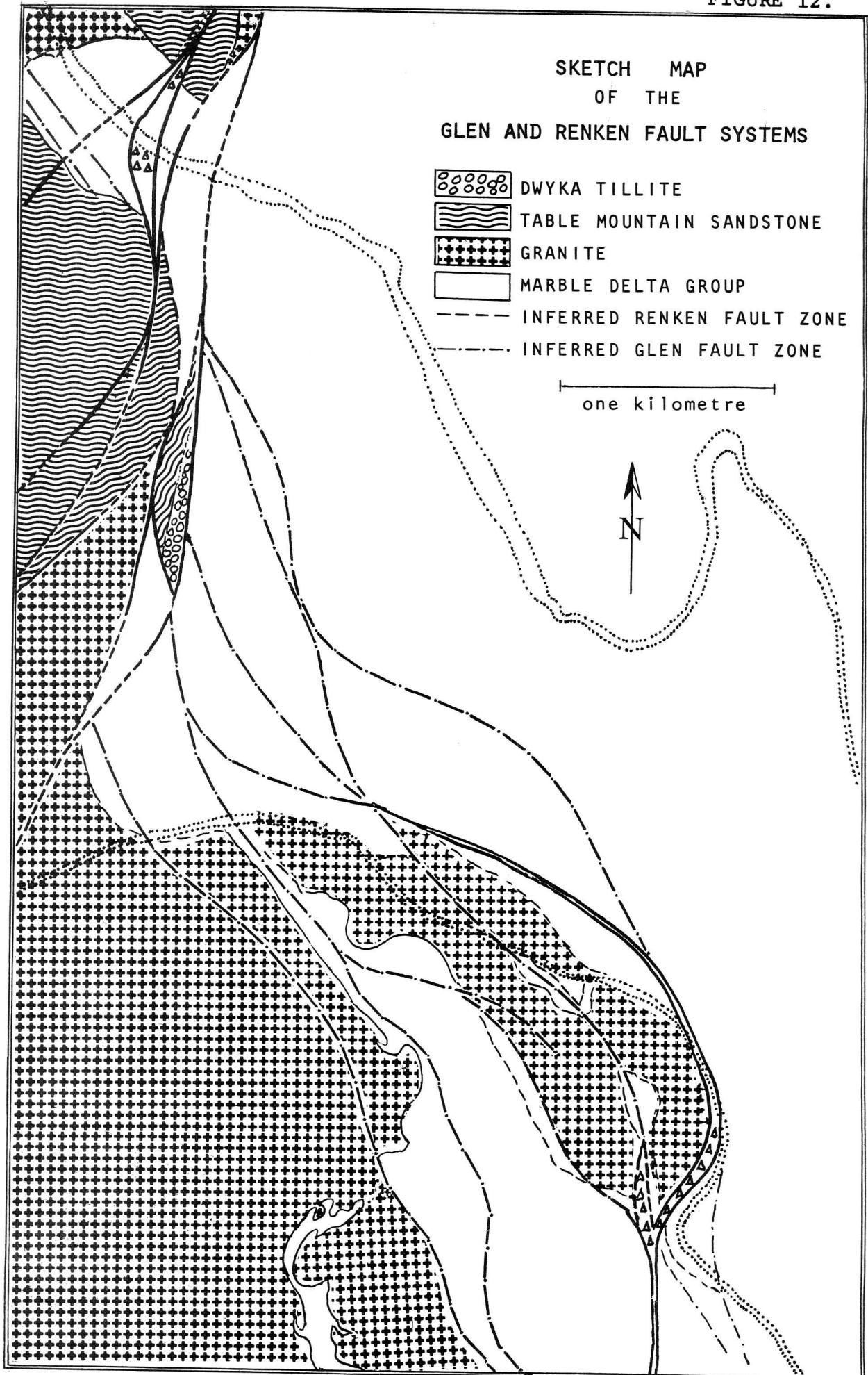
Two very prominent zones of cataclastic deformation of pre-Cape age are present in the southern part of the Marble Delta, separating the main mass from the southern outliers on Lot F N, The Glen and Lynwood. The greatest displacement is represented by a broad zone of altered and crushed rock about 600 m wide (site 11 T). It starts in the south on The Glen as a prominent quartz outcrop and a fault breccia can be seen in the Umzimkulwana River (site 11 U). The Umzimkulwana River followed the fault zone and is parallel to the quartz-rich fault-breccia between The Glen and the boundary of Lot F N and The Forest. The fault splits into several minor ones as evidenced by the brown dolomite replacement bodies and by deeply weathered zones with brown, yellow and bluish chert. Between Lot F N hill and Lynwood another major fault is suspected from the zone of replacement dolomite and dolerite at the contact of marble and granite (fig. 12). The net result of the movements along the whole fault system is that the marble outliers represent successively deeper levels towards the south-west.

The Renken Fault

The major dislocation of post-Cape age is the composite Renken fault which enters the area from the north. According to Du Toit (1946) the fault has a downthrow of about 600 m to the west at the Equaleni River about 10 km to the

north-west/

FIGURE 12.



north-west.

In the Marble Delta the Renken Fault was found to comprise several blocks mainly in the form of a graben. The zone of intense faulting is about 600 m wide. None of the major fault planes is exposed but a 100 metre wide breccia occurs on the south bank of the Umzimkulu River (fig. 12). The breccia consists of fragments a few cm in diameter and blocks up to several metres in length. The dip on slickensides is about 25° to the north. A similar breccia occurs along the Oribi Gorge road and contains large blocks dipping up to 68° northward. Between the two abovementioned breccia localities the valley is underlain by down-faulted Table Mountain Sandstone varying in dip from 2° to 45° indicating separate compartments of the graben.

Dwyka Tillite crops out next to the marble (Map 1, 3k) and lies on Table Mountain Sandstone dipping about 45° to the east. It was dropped down about 500 m into the graben on the eastern side. If Du Toit's downthrow of 600 m to the west at Equaleni is maintained, then the Dwyka Tillite must have had a total displacement of 1100 m at this locality. However, it appears certain that the displacement along the Renken fault is much less in the Marble Delta.

The tilted blocks of Table Mountain Sandstone more than 100 m in length extend into the granite area to the south and can therefore not be ascribed to collapse into underlying cavernous marble. The fault blocks usually have a shear plane on either side and since they are tilted the faults are of the antithetic type while those parallel to

the master fault are called synthetic faults.

Similar graben-like fault systems were mapped by the writer in the Queensburgh area of Durban. The arrangement of these fault systems seems to be related to the orientation of the erosional window of basement rocks along the crest of what was formerly regarded as the Natal Monocline. Maud (1962) reviewed the "monoclinial theory" and concluded that it does not adequately explain the structural pattern of Coastal Natal. He regarded the structure as one of step-faulted tilted blocks analogous to that of the Zoutpansberg. Hardie (1962) experimented with a clay model which produced fracture patterns similar to those of Coastal Natal and suggested that the faults are all related to one period of tensional deformation. His experiment is of significance in that it produced analogous graben-like features. However, the total displacements of the faults appear to be too small to account for the erosional window of basement rocks. Furthermore, the fact that the basement rocks occupied a topographic highland during deposition of the Table Mountain Sandstone suggests that the tensile stress pattern developed on a pre-existing pre-Cape structure, as exemplified by the faults in the Marble Delta area.

IX PETROGENESIS

The Marble Delta poses numerous unsolved problems in metamorphic and igneous petrology as well as structural geology and sedimentology. It is usually extraordinarily difficult to reconstruct the environment of deposition of such an ancient metamorphosed succession and this will not be attempted in detail. The origin of the graphite marble, of various amphibolites, the effects of repeated metamorphism and the associated injection of granites into marbles of variable composition are subjects of special interest to the author.

1. Sedimentation

Apart from the dolomitic replacement bodies and some siliceous rocks, all the marbles and quartzites of the Marble Delta were unquestionably derived from sediments. Although the upper and basal parts are missing, a normal sedimentary sequence starting with clastic deposits followed by dolomitic beds passing upwards into limestone is indicated. Some marble units are distinctive and can still be recognised as lithostratigraphic zones, for example the calc-silicate marble contrasts with the cluster serpentine marble in form and composition, despite intensive metamorphism and flowage. Sedimentary features have also been preserved in the meta-quartzites: some appear to have had a gritty texture whilst the smooth and scalloped types may represent original cherty layers. Instability of the basin floor during sedimentation may have affected the kind of material which was deposited;

this is indicated by the variable nature and thickness of metaquartzites, the local presence of a conglomerate and the fact that thin marble beds associated with amphibolite are found up to 38 km west of the Marble Delta.

Deposition of the Marble Delta Group was dominated by calcareous beds but evidence of minor intercalations of impure sediments which may be of genetic significance exists. Thin partings now marked by a row of pale pink spinel octahedra along the bedding trace must have represented highly aluminous layers. Phlogopite bands (distinct from metaconskarns), phlogopite-calcite marble and phlogopite-cummingtonite-microcline layers are derived from potash-rich sediments. Dravite-phlogopite marble indicates that boron may have been fixed in mixed layer illitic clay in the depositional environment. However, this is not reliable as a paleosalinity indicator since adsorbed boron does not necessarily retain its relationship to depositional salinity during diagenesis and recycled illite may result in an additional boron contribution (Perry, 1972).

In an attempt to determine the original composition of the calcareous sediments, the available chemical analyses of the marble were recalculated to SiO_2 , CaCO_3 and $\text{CaMg}(\text{CO}_3)_2$ and plotted on the ternary diagram (fig. 13). This procedure is justified by the fact that no evidence of large scale migration of Si, Mg or Ca during metamorphism was found and isochemical transformation can thus be assumed, except for the loss of CO_2 . Forsterite, diopside, tremolite and wollastonite formed in place except in close

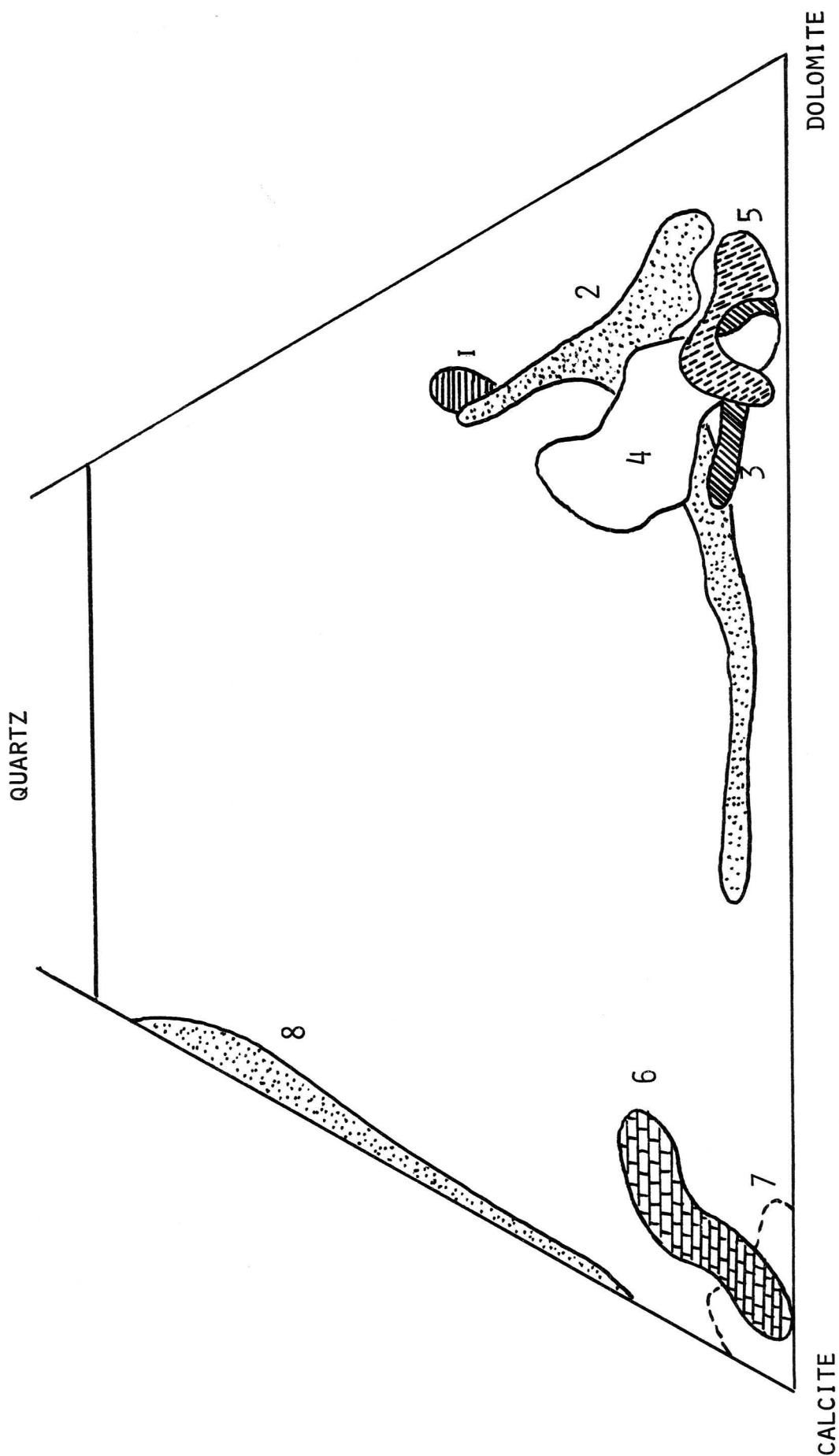


FIGURE 13. Diagram showing compositional fields of original calcareous sediments as calculated from analyses of various marble units in Marble Delta.

- 1. Calc-silicate marble beds
- 2. Cluster serpentine marble
- 3. Dolomite marble beds (Lot F O)
- 4. Banded calc-silicate marble (MM 166)
- 5. Dolomite marble (Upper Le Joncquet For.)
- 6. Calcite marble (Lower Oribi Formation)
- 7. Calcite marble (Upper Oribi Formation)
- 8. Quartz-calcite marble

proximity to granite dykes or amphibolite, where metasomatic exchange has occurred. Even where considerable mobilization of a marble bed has taken place the chemistry remains remarkably constant. Thus minute silicate layers were also broken up in the flow process but remained essentially in place. The total SiO_2 , therefore, represents the approximate percentage of the original silica in the sediment. Free quartz as blebs which persisted in the marble due to high X_{CO_2} in the semiclosed system during the peak period of metamorphism is identifiable with its original lithostratigraphic interface. In figure 13 the distribution fields of the reconstituted calcareous sediments are shown. A notable concentration of calcite between 12 and 20 per cent appears in the dolomitic sediments. This seems to confirm the suggestion that interstitial calcite present in dolomite rock was due to an original chemical control in the sedimentary basin where calcite was precipitated with dolomite.

As described in chapter III.4. facies variation in the Marble Delta Group is mainly reflected by an increase in the silica content of the calcite marble in an easterly direction. Much more prominent is the vertical change-over from the dolomitic composition of the Le Jonquet Formation to the predominantly calcitic marble of the Oribi Formation. A similar change is known in the unmetamorphosed Campbell Rand Dolomite Formation of the Danielskuil area where evidence of dolomitization has been found (Toens, 1966) and also of intermittent precipitation of dolomite and calcite. In the

Marble Delta there is no indication of dolomitization except replacement by dolomite after metamorphism. It therefore seems probable that limestone and dolomite were originally precipitated as such.

Peculiar nodular structures have been recognised in the cluster serpentine marble of the Le Jonquet Formation and rare concentric structures are found in metaquartzite on Westlands. The question arises to what extent biogenic agencies played a part in the deposition of the Marble Delta Group.

Graphite is present in the marble as distinct layers, concentrations in calc-silicate clusters, along skarn and granite contacts and in amphibolite. The origin of this graphite may be ascribed to one or more of the following processes:

- (i) Precipitation from the primordial atmosphere.
- (ii) Derivation of carbon from living organisms.
- (iii) Reduction of CO_2 in limestone during metamorphism.

Studies on the isotopic composition of carbon have been undertaken with a view to distinguish between carbon of biogenic and nonbiogenic origin, especially in ancient rocks (Craig, 1953, 1954; Rankama, 1954). So far the results do not appear to provide a reliable indicator of the source of the graphite without further geological information. The interpretation of carbon isotope work is complicated by the possibility that graphite may have formed along granite contacts both from carbonaceous matter and through the reduction of the CO_3^{--} radical. Pitcher (1950) described

the redistribution of graphite flakes along a skarn vein by means of reversible reactions between carbon and water or CO_2 . Rao and Rao (1970) described a similar piling-up of graphite along the contact of a calc-silicate skarn. They suggested that the CO_2 released by the formation of silicates was augmented by CO_2 derived from sporadic graphite by reaction with water from a granitic source and that the CO_2 was subsequently reduced to graphite. It is not clear to what extent CO_2 from each of the two different sources (CO_3^{--} and pre-existing C) contributed to the final concentration of graphite in the marble.

The following arguments can be advanced that the graphite in the Marble Delta was derived from carbonaceous matter originally deposited together with the sediments:

1. Graphite layers and graphitic bands are parallel to the relic bedding.
2. Graphite layers maintain a relatively constant thickness over a distance of several metres irrespective of the amount of disseminated graphite specks in adjacent marble (Plate IX, ph 2). The thickness of these bands would not represent the original thickness of carbonaceous layers as they were affected by stretching due to flow folding.
3. The graphitic bands show a progressive increase in number and thickness in the Le Jonquet Formation from the calc-silicate marble to the dolomite marble, reaching a maximum between Bed Nos. 6907 - 6931 (fig. 2).
4. The first prominent appearance of graphite layers is in
the/

the lower Oribi Formation, maximum thicknesses being attained between Beds 3447 and 3801.

5. Repetitions of the graphitic (and graphite) bands associated with siliceous bands and their continuity through zones of differential flowage and variable intensity of metamorphism indicate stratigraphic control.

6. Small but conspicuous flakes are disseminated in certain metaquartzite units of sedimentary origin.

The fact that the carbonaceous deposits became prominent only after the major change from dolomite to limestone deposition appears to be symptomatic of sedimentary environments. Apparently, similar conditions prevailed during the change-over in the Campbell Rand Formation of the Transvaal Supergroup. In the Danielskuil area up to 30 cm thick carbonaceous layers alternate with poorly developed, as well as thin, well-formed but genetically different species of stromatolites in the limestone. This is in contrast with the prodigious development of stromatolites in the underlying dolomite. It seems that the formation of carbonaceous matter, both at Danielskuil and in the less well-preserved Marble Delta Group, is related to a change in the sedimentological and biological conditions marked by a decline of the bioherms. The cluster-type of marble of the upper Le Jonquet Formation may represent the metamorphosed equivalent of a sediment containing proto-stromatolitic forms of life.

It is therefore concluded that the greater part of the graphite originated not through the breakdown of carbonates during metamorphism but by metamorphism of sedimentary carbonaceous material. It is further suggested that the

graphite/

graphite associated with the pneumatolytic and "magmatic" quartz veinlets was transported in ionic form after assimilation of pre-existing graphite. Granites close to major graphite occurrences also contain graphite flakes and graphite forms part of the mineral assemblage in certain contact skarns. The clinopyroxene-calcite marble derived its irregular patches of graphite by incorporating the original graphitic bands and this recrystallized as graphite after the cessation of movement on the southern side of the Umzimkulu River. On the north bank flowage resulted in bands of augitic pyroxene and zones of graphite, indicating once again that carbon was not derived from the carbonate.

A period of erosion intervened between the deposition of the Oribi and Cherrywillingham Formations and a radical change in the environment probably occurred at this stage. Apart from minor intercalations of pelitic and psammitic sediments and well-banded amphibolites, probably of tuffaceous origin, the Cherrywillingham Formation consists predominantly of amphibolite, the origin of which remains to be discussed in comparison with that of the other amphibolitic rocks in the Marble Delta.

2. Origin of amphibolite

Massive amphibolite occurs in the form of sills and dykes intrusive into the marble. Layered amphibolite is found interbedded in the Oribi Formation and greater part of the Cherrywillingham Formation, showing that at least two main types of amphibolite are present in the Marble Delta.

Simpson and Tregidga (1956) regarded the majority of amphibolites as basic sills modified by regional metamorphism under temperature and pressure conditions typical of the amphibolite facies. However, petrological problems concerning the genesis of amphibolite have not been solved and the following hypotheses must be taken into account:

1. Igneous origin: (a) basalt + water
(b) basalt + metamorphism
2. Sedimentary origin: (a) dolomitic pelites + metamorphism
(b) greywacke + metamorphism
3. Origin by metasomatism

A number of workers undertook chemical studies in an endeavour to determine whether amphibolites are metasediments, meta-igneous rocks or of metasomatic origin. Para-amphibolites have been shown by Wilcox and Poldervaart (1958) to exist, and Rivalenti and Sighinolfi (1969) suggest an origin by metamorphic transformation of greywackes. An igneous origin has been suggested because amphibolites plot on the differentiation trends of basalts (Evans and Leake, 1960; Leake, 1964; Engel and Engel, 1962). Other workers have shown that amphibolites can be produced by metasomatic processes during metamorphism of calcareous sediments (Orville, 1969; Vidale, 1969), causing banding through metamorphic differentiation. On a small scale a diopside granofels was amphibolitized by metasomatic reactions (Smithson et al., 1971).

Chemical analyses of the Marble Delta amphibolites were given in Table 6. When the niggli values are plotted on

the al-alk against c diagram they fall within the field of the Karoo dolerite and the Connemara striped amphibolites (Evans and Leake, 1960). The Lot 21 amphibolite (Table 6, Anal No. 3) when plotted on Evans' diagram, falls within the dolomitic greywacke field. Evans and Leake (1960) pointed out that the trend of igneous rocks on this diagram is at right angles to the clay-dolomite line in the Niggli diagram. The niggli values mg plotted against c fall on the trend line of the Karoo dolerites (Leake, 1964, fig. 1) at a position between the middle stage and early differentiates, but the Lot 21 amphibolite again falls within the field of the pelite-dolomite mixture. Nevertheless it is an intrusion (cf. Simpson and Tregidga, 1956, fig. 1), situated on strike of a nelsonitic amphibolite dyke. The chemical evidence is therefore regarded as inconclusive. Other authors have also cast considerable doubt on the adequacy of variation diagrams as a means of distinguishing between amphibolites of igneous and sedimentary origin. Calculations based on chemical analyses are time-consuming and of little avail since it has been shown, furthermore, that "amphibolite" (or amphiboles) which originated by metasomatism may also fall on the "igneous" trend lines.

In the Marble Delta products of metasomatic reactions are present in very localised zones. These reactions have taken place over very short distances (less than 1 cm or within crystal cluster size), except when associated with intrusives with the production of amphiboles forming typical skarn rock such as recorded in the skarn classification.

Metasomatism cannot be held responsible for the layered structure of the Cherrywillingham amphibolites.

The layering is primary and was accentuated by metamorphic minerals. This metamorphic differentiation without large scale metasomatism is paralleled by thin intercalations of calcite marble and contrasts with the dyke material which has been shielded in places from granite intrusions by calcite marble; where the dykes are intersected by the granite, metasomatism and granitization have taken place (fig. 10). In such cases isolated migmatite bodies have been produced which are orientated parallel to the original structure of the amphibolite. It seems doubtful whether amphibolization could be demonstrated to have taken place on a large scale by metasomatism to form thick layers such as those present in the Marble Delta in areas of high-grade metamorphism where metamorphism reached the granulite facies.

Metamorphism of pelitic calcareous or greywacke sediments is a possible mode of origin of the Cherrywillingham amphibolites since beds with the requisite composition undoubtedly existed and are now, in part, represented by granulites. The layered amphibolites, whether regarded as original tuffs, lavas, sills or sediments, have a chemistry similar to the amphibolite dykes. These are undoubtedly magmatic but the question remains whether they originally crystallized as dolerites or not.

Yoder and Tilley (1962) suggested that basaltic magmas with a high water content could crystallize as amphibolite

or hornblende. Wilcox and Poldervaart (1958) also considered the possibility that amphibolite may have crystallized directly from a magma. Yoder and Tilley (1962) demonstrated in experimental work that amphibolite may readily form over a wide range of temperature and pressure. The conversion from basalt to amphibolite involves the addition of water which must result in a change of volume. This may well be the case where intrusive sheets were emplaced in layered sediments or tuffs which readily lend themselves to this type of reaction when sufficient water is available and which would explain the coarse-grained texture during recrystallization, e.g. the Lot F 0 amphibolite with hypersthene. (Analogous conditions may have applied to the emplacement of ophiolite sheets in geosynclinal Otavi-Damara sediments in the Kaokoveld).

According to the CIPW classification the Cherrywillingham amphibolites fall within the basanite to olivine-basalt fields. Whether these rocks were intruded or extruded, large quantities of water would have been needed and this was certainly not available for the amphibolite dykes in the calcite or dolomite marble. Therefore opposite conditions are envisaged for the dykes and sheets present in the marble: they must have crystallized primarily as amphibolites and are not due to recrystallization of basalt during the ensuing high-grade metamorphism.

Yoder and Tilley (1962) have shown that the stability field of basalt is considerably reduced in the presence of water and that amphibolite is produced. This is suggestive

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that large amounts of water could have accompanied basalt intrusion in the Marble Delta. The amphibolite dyke (130 Level, H 220) plots within the alkali basalt field on the total alkalies vs silica diagram (MacDonald and Katsura, 1964). The same result is obtained by plotting the amphibolites on the total alkalies vs alumina diagram (Kuno, 1960). In these diagrams the amphibolites show a trend in the same direction as that of the 13-18 kb experimental data of Green and Ringwood (1967) from tholeiite to the alkali basalt field. In conjunction with the field evidence of intrusion, this suggests that the amphibolites of the Marble Delta are of basaltic origin and possibly originated from a relatively low level in the upper mantle.

The magmatic hypothesis accords well with observations on the amphibolite bodies of undoubted intrusive origin in the Marble Delta. Thus the parallelism of dykelet walls indicates shallow intrusion along joints and bedding planes: the retention of relatively fine-grained textures in narrow dykes as compared with wider dykes and sheets is regarded as evidence of original chilling; and negligible contact metamorphism (if recrystallization had taken place during high grade metamorphism, considerable contact reaction effects should have been present) point towards a low temperature of intrusion (Plate XXIV, ph 2).

3. Metamorphism

The Marble Delta can be regarded as a xenolithic mass surrounded and intruded by several ages of igneous rocks.

Du Toit (1946) held metamorphism by granites to be responsible for the transformation of limestone and dolomite into coarse-grained marbles. Simpson and Tregidga (1956) concluded that the "dolomitic limestones" suffered regional metamorphism under conditions typical of the amphibolite facies, which also prevailed during emplacement of the eastern and western gneisses and which transformed basic sills into amphibolite. They also postulated a higher grade of metamorphism approaching the granulite facies for the production of the charnockitic suite, and ascribed the intrusive granites to a final process of anatexis accompanied by limited contact effects.

Field relationships and mineral assemblages observed by the present author led him to believe that granites with characteristic thermal effects have invaded relatively cold, anhydrous marbles with a previous metamorphic history, and eventually produced retrograde metamorphism by the re-introduction of water and the crystallisation of minerals like talc and serpentine. The superimposed, polyphase contact metamorphism took place under varying equilibrium conditions (with T and P_{CO_2} as principal intensive variants) and to a large extent masked the earlier regional metamorphism. The latter can only be reconstructed from geological criteria such as crosscutting intrusives and the inter-relationship of relict structures and mineral assemblages.

During the protracted metamorphic history of the area the physical factors including P - T conditions which affected the formation of mineral assemblages changed continuously.

For example, where water was progressively expelled the effective increase in X_{CO_2} may have caused the reactions to become univariant while in adjacent marble associated with amphibolite the reactions were bivariant. Similarly, different conditions may be postulated for the different ages of wollastonite: one at low temperatures associated with induced contact metamorphism and another under high temperature regional metamorphism of pre-granite age (in the Le Joncquet area). Wollastonite is certainly not everywhere attributable to the proximity of intrusive granite (Simpson and Tregidga, 1956). Magmatic quartz dykelets show contact reactions with calcite wall-rock without the formation of wollastonite. This can only be explained by the attainment of semi-closed conditions which prevented the escape of CO_2 and shifted the $\text{Cc} - \text{Qz} - \text{Wo} - \text{CO}_2$ equilibrium to the left. These conditions apply equally well to the quartz-calcite marble in East Slopes Quarry, situated quite close to a wollastonite body in the marble (Plate V, pm 1). Semi-closed conditions are also taken as a pre-requisite for the formation of the myrmekites described under granite dykes.

It should be clear that the application of mineralogical criteria for the facies concept becomes difficult under circumstances of polyphase metamorphism and lack of equilibrium. According to Fyfe, Turner and Verhoogen (1958) metamorphic facies and its genetic interpretation has led to much confusion in the past. Lambert (1965) suggested that inferences from equilibrium relationships with regard to

conditions/

conditions of metamorphism should be omitted and that sub-facies should not be used at all. In a reappraisal of Eskola's original concept, Fyfe and Turner (1966) suggested that facies should be defined solely in terms of observable geological criteria. Although Winkler (1967) considered that subfacies should provide the basis of petrogenetic considerations, he proposed the abolition of metamorphic facies three years later (1970). The most that can be said about the facies of regional metamorphism in the Marble Delta is that the upper amphibolite or lower granulite facies has probably been reached. This is based on the occurrence of forsterite-calcite-dolomite marble in the central area relatively free of granite intrusions and on the grossularite-bearing granulites of the Cherrywillingham Formation. The presence of tremolite as large clusters in the same vicinity and along the eastern part of Le Joncquet is indicative of non-equilibrium and the retention of a hydrous phase earlier than the emplacement of the Westlands and Buffalo Bill granites.

According to Winkler (1967) the temperature of origin of charnockites and the granulites of the granulite facies may have been as high as 800°C. Goldsmith and Newton (1969) concluded from experiments that the calcite-dolomite solvus can be a very useful geothermometer for metamorphic calcite, especially if the depth of the metamorphism can be categorized as to shallow, intermediate or deep. Carpenter (1967) proposes a minimum temperature of 760° - 800°C and 700 bars CO₂ pressure for the metamorphism of the marble

at Crestmore, California, based on the total amount of MgCO_3 , some contained in dolomite exsolution lamellae, that he deduces to have been in solid solution in the calcite. Identical exsolution textures are present in certain calcite marble beds of the Marble Delta, but these differ from Crestmore in the absence of periclase. The fact that the Marble Delta calcite generally contains less than 1% MgCO_3 might be interpreted as the result of virtually complete exsolution of noncoherent type. However, evidence was also presented that calcite and dolomite were originally deposited together (chapter IX 1). Caution is therefore necessary in applying the calcite-dolomite geothermometer to the Marble Delta and detailed study of the problem is needed.

The theory that the Oribi Gorge charnockitic suite originated by transformation of basic rocks is rejected. The granites of which they form part post-date the F_2 folding and the period of high-grade regional metamorphism. Furthermore, dioritic and gabbroic inclusions of the much older N'Dongeni suite have been preserved in the St. Faith's granite (probably post-dating F_1) and were obviously not altered by high-grade regional metamorphism as postulated by Simpson and Tregidga (1956) for the charnockitic suite.

Contact metamorphic aureoles cannot be outlined regionally since the whole area is riddled with intrusives. However, contact zones are recognizable in the immediate vicinity of granites where temperatures exceeded the stability range of minerals produced by an earlier metamorphism. This is typical of the Westlands and Buffalo Bill granites

where/

where contact reactions took place under conditions approaching a closed system as indicated by the absence of wollastonite and the presence of clinopyroxene. In the eastern part of the Marble Delta, however, a higher grade of metamorphism is evident through the development of large white diopside crystals and massive wollastonite bodies. This may be due to contact metamorphism by The Wolds garnetiferous granite. Large (3 cm) garnets also developed in amphibolite inclusions within the granite. Close to the contact of the St. Faith's granite again, the granulitic rocks of the Cherrywillingham Formation contain cordierite-almandine assemblages. Amphibolite dykes do not show high temperature reaction zones with the marble except for the induced contact metamorphism caused by granite which heated the wall-rock immediately next to the dykes (Plate XXIV, ph 2).

Zoning of minerals is not normally expected in a metamorphic terrain as recrystallization proceeds with a continuous adjustment of equilibrium. With a rapid rise in temperatures metastable sequences may develop. However, the zoned plagioclase crystals in altered amphibolite are not metastable relics but developed as a result of contact metamorphism during the waning stage of the intrusion (Buffalo Bill granite) before equilibrium could be established. The zoning of cummingtonite associated with microcline is due to diadochy of Mg and Fe probably under regional metamorphic conditions.

Retrograde metamorphism developed extensively to the south and in the eastern part of the Lot F A 3 and Le Jonquet areas. The characteristic minerals are chrysotile,

talc/

talc and serpentine. The serpentine associated with con-skarns is regarded either as deuteritic or as the result of late magmatic movement along contacts.

4. Emplacement of Granites

The ages and relative depths of granite emplacement can be deduced from the type of contact reaction zones with respect to P_{CO_2} and from the mechanics of intrusion. For example magma which followed joint planes in the marble indicates a shallow intrusion. The greater the depth and the heat imparted to the marble the greater is the amount of flowage of the wall-rock. These field criteria separate the Westlands granite and Buffalo Bill granites in time and indicate that the Westlands granite is a shallower (or cooler) intrusion.

The emplacement of the Oribi Gorge porphyritic granite (called western gneisses by Simpson and Tregidga, 1956) was clearly a magmatic process as evidenced by the large stoped rafts of The Wolds gneissic granite. The angular fragments of The Wolds granite included at one locality (Map 1, 4W 4121) support this contention. The fact that the xenolithic bodies are still clearly recognisable with preservation of their original structure indicates that post-emplacement tectonism in this area was absent or weak.

The later granite-offshoots within the marble are generally devoid of garnet. The Wolds granite contains a high percentage of garnet right up to the contact with the marble. Garnet is also present in the large offshoot from the Oribi

Gorge granite on Simuma and The Forest. It seems that the deeper levels and longer periods of intrusion produced more garnet than the northern, later and shallower intrusions of granite which are notable for the crystallization of Fe-clinopyroxenes.

No field evidence for transformation in place has been found except for small-scale granitization effects produced by the invading granite. In amphibolite this process was analogous to migmatization with the appearance of partial melting in the final product. That it was produced by a magma is proved conclusively by the fact that blocks of amphibolite were transected by granite at the same time. In parts the amphibolite has been changed to hybrid granite with porphyroblasts of potash feldspar. Amphibolite blocks missed by the intrusion and sealed off by calcite marble, remained unaltered except for the induced skarn on the contact although they experienced the same temperature and pressure as the "migmatite".

In conclusion the structure of the granites, especially the foliation of the St. Faith's granite with its pronounced southward dip and approximate west-northwesterly strike, is parallel to the general trend of the marble as well as the metasediments in the east. This trend is subparallel to the strike of the metasediments and marble near Harding and roughly coincides with the Bouguer anomalies (1 : 1 000 000 (1 : 1 000 000 Geological Map of South Africa). The structural evidence is therefore in agreement with sparse geochronological data that link the Marble Delta area with the Namaqua-Natal mobile belt.

X SUMMARY AND CONCLUSIONS

1. The stratigraphic succession of the Marble Delta Group can be subdivided into three Formations on lithostratigraphic grounds.
2. Du Toit's quartzite marker swings northward instead of continuing westward; as a result the lower part of the succession is more extensive than previously thought.
3. The calcitization process proposed by Du Toit (1920, 1946) to explain the association of granite with calcite wall-rock is considered rare or absent. Calcite marble occurs as stratigraphic units and these are preferentially intruded by granite.
4. Dolomitization was found to be only applicable to late pre-Cape replacement bodies which are not part of the proper stratigraphic sequence as described in the literature.
5. Graphite in the marble is considered to be of biogenetic origin as opposed to atmospheric precipitation or generation of carbon by the breakdown of the CO_3^{--} radical during metamorphism.
6. Metasomatic replacement occurred on a very limited scale in the marble and the distance of diffusion was not much greater than the size of a crystal. This is evident from relic bedding in which Al, Fe and Si remained in place. Apart from CO_2 loss through repeated metamorphism the greatest movement of volatile constituents was produced by metasomatic fluids emanating from granite magma to form clinohumite, chondrodite, scapolite, serpentine and

chrysotile/

chrysotile. The size of the metasomatic aureole was found to depend on fugacity conditions associated with the magma and not on the size of the intrusive body.

7. The application of existing definitions of the term skarn is unsatisfactory when a genetic meaning is implied; it is therefore redefined in a purely descriptive sense and a classification of genetic types is given.

8. Three types of metamorphism have been recognized viz. regional metamorphism possibly of upper amphibolite to granulite facies, repeated contact metamorphism and minor retrograde metamorphism. Geological criteria based on structural relationships were used to distinguish as far as possible between these episodes. The marbles were already coarse-grained before the intrusion of granites.

9. Several ages of granite ranging from gneissic to fine-grained to porphyritic types can be distinguished. These were emplaced at various times and levels in the crust.

10. A suite of gabbros, diorites, monzonites and alkaline rocks (not previously described) are unaffected by high grade metamorphism; such a mechanism for the origin of the Oribi Gorge charnockitic rocks is rejected.

11. Relic s-surfaces of F_1 folding have been recognised in marble and especially in quartzitic layers with contorted diopside laminations and in local conglomeratic facies with deformed pebbles.

12. A later (F_2) period of folding is held responsible for the regional distribution of rock-types which, together with the orientation of lineation, revealed a major dome

structure modified by several irregular synforms and anti-forms.

13. Petrofabrics of metamorphic minerals in the marble can only be used to determine localized stress patterns related to a specific metamorphic episode and have little significance with regard to the development of fold structures. During flowage, recrystallization rather than gliding or translation within calcite or dolomite grains takes place.

14. The numerous separate bodies of granite that were emplaced in the marble provide a unique opportunity of studying mineral assemblages formed under different PTX conditions. With waning temperatures these assemblages were often preserved in closed-off systems like those of the laboratory. The closed or semi-closed conditions are thought to develop in the following manner. Initially, calcite is corroded leading to the incorporation of Ca^{++} in the magma and the liberation of CO_2 . Such assimilation is soon terminated as the escape of CO_2 is prevented by increased ductility of the wall-rock in response to rising temperature. Thus, with rising X_{CO_2} in the system the magma becomes encased in non-reactive marble, giving controlled conditions which facilitate the interpretation of petrological events. For example, high P_{CO_2} may depress the $P_{\text{H}_2\text{O}}$ in a magma to such an extent that crystallization takes place under a low oxygen fugacity which may lead to pyroxene-bearing or so-called dry granites.

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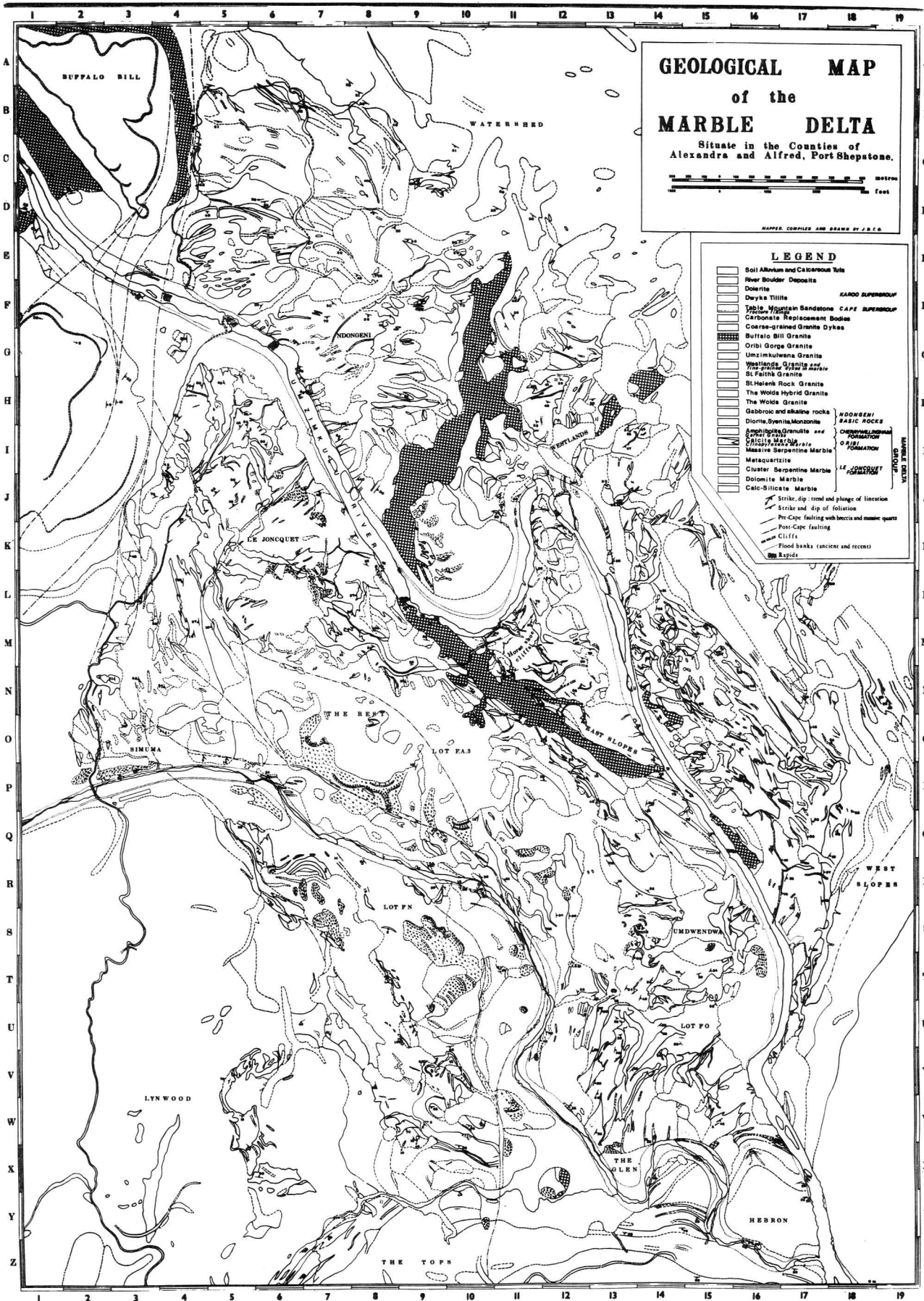
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GEOLOGICAL MAP of the CALCITE QUARRIES, LE JONCQUET

SCALE 1:50,000

LEGEND

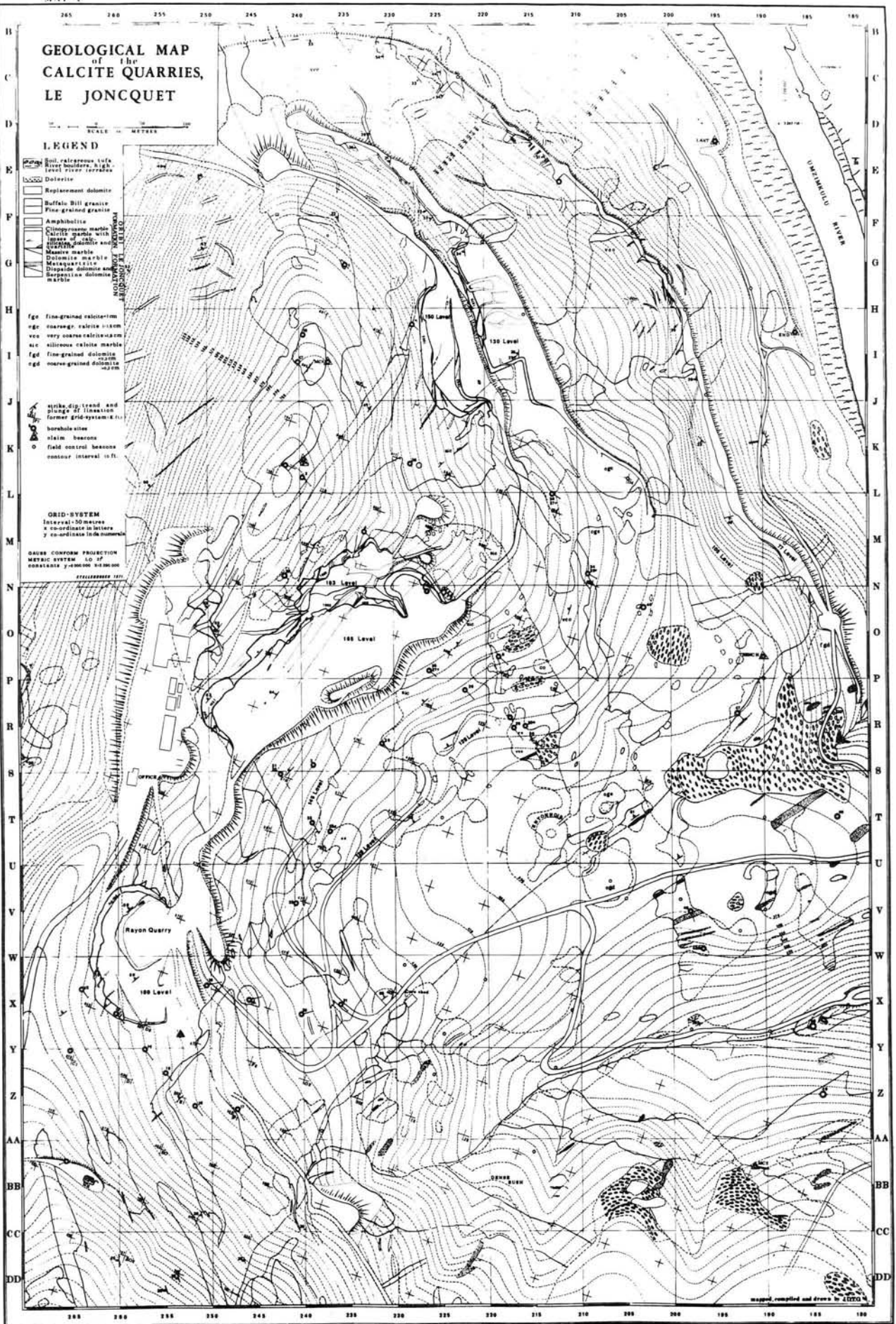
- Soil, calcareous tuff
- River boundary, high-level river terraces
- Dolomite
- Replacement dolomite
- Buffalo Hill granite
- Fine-grained granite
- Amphibolite
- Clingstone marble
- Marble with layers of calcite and quartzite
- Massive marble
- Dolomite marble
- Metagranite
- Diabase dolomite and serpentinite dolomite
- Marble

- fgs fine-grained calcite-tuff
- rgr coarse-grained calcite-tuff
- vgc very coarse calcite-tuff
- msc siliceous calcite marble
- fgd fine-grained dolomite
- rgd coarse-grained dolomite

- strike-slip trend and plunge of lineation
- former grid-system (1:1)
- hand-drawn lineation
- claim boundary
- field control boundary
- contour interval 10 ft

GRID-SYSTEM
Interval: 50 metres
x co-ordinate in letters
y co-ordinate in numbers

GRID CONFORM PROJECTION
METRIC SYSTEM: U.S. OF AMERICA
PROJECTION: UTM
SCALE: 1:50,000



MAP 3

